Report Title: **Cornice Duct System**

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DISCLAIMER:

EXECUTIVE SUMMARY

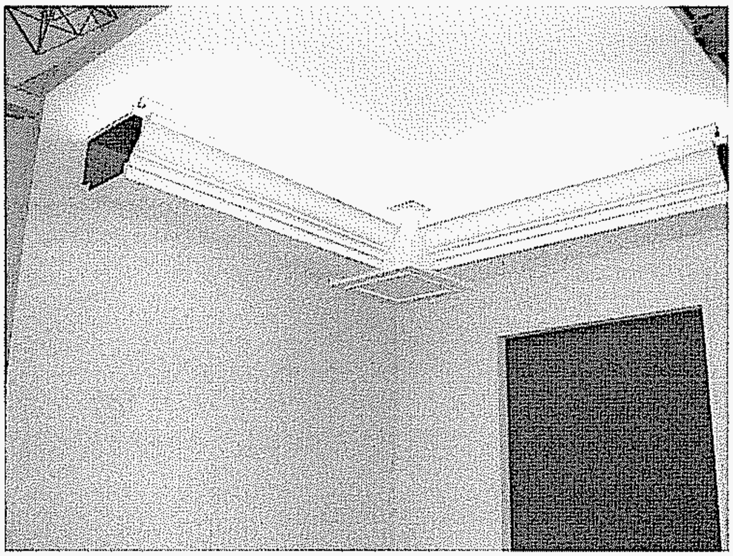
Current residential construction in the United States is based overwhelmingly on wood framing. This system is very efficient structurally and very economical to build. However, the system was developed before the advent of central heating and cooling. As a consequence, the system never had a provision for thermal air distribution. The "patch" to the system has been to run ducts through unconditioned attics and crawlspaces, where 30 to 40% of the energy can be lost before the air arrives at the conditioned space. These losses could be eliminated by brining the air distribution ducts internal to the thermal envelope of the residence. Typical commercial methods for dealing with this problem, such as hiding the ducts above a hung ceiling, have not proven to be aesthetically acceptable in the residential market. This project is directed at developing a product that will be aesthetically compatible with residential visual standards, while keeping the ducts internal to the conditioned space.

SYNERGETICS, Inc., has designed, developed, and tested an air handling duct system that integrates the air duct with the cornice trim of interior spaces. The device has the advantage that the normal thermal losses from ducts into unconditioned attics and crawlspaces can be totally eliminated by bringing the ducts internal to the conditioned space. This report details work conducted to develop the Cornice Duct System into a viable product for use in a variety of residential or small commercial building settings.

A full-scale prototype was fabricated and tested in a laboratory test building at the Daylighting Facility at North Carolina State University. Based on the results of that testing, the prototype design was refined, fabricated, installed, and extensively tested in a residential laboratory house. The testing indicates that the device gives substantially superior performance to a standard air distribution system in terms of energy performance and thermal comfort. Patent Number US 6,511,373 B2 has been granted on the version of the device installed and tested in the laboratory house. Refinements to the device have been carried through two additional design iterations, with a particular focus on reducing installation time and cost and refining the air control system. These new designs have been fabricated and tested and show substantial promise. Based on these design and testing iterations, a final design is presented in this report. That final design is the basis for a continuation in part that has been filed with the U.S. Patent Office.

ABSTRACT

SYNERGETICS, INC., has designed, developed, and tested an air handling duct system that integrates the air duct with the cornice trim of interior spaces.



The device has the advantage that the normal thermal losses from ducts into unconditioned attics and crawl spaces can be totally eliminated by bringing the ducts internal to the conditioned space. The following report details work conducted in the second budget period to develop the Cornice Duct System into a viable product for use in a variety of residential or small commercial building settings. A full-scale prototype has been fabricated and tested in a laboratory test building at the Daylighting Facility at North Carolina State University. Based on the results of that testing, the prototype design as been refined, fabricated, installed, and extensively tested in a residential laboratory house. The testing indicates that the device gives substantially superior performance to a standard air distribution system in terms of energy performance and thermal comfort. Patent Number US 6,511,373 B2 has been granted on the version of the device installed and tested in the laboratory house. (A copy of that patent is attached.) Refinements to the device have been carried through two additional design iterations, with a particular focus on reducing installation time and cost and refining the air control system. These new designs have been fabricated and tested and show substantial promise. Based on these design and testing iterations, a final design is proposed as part of this document. That final design is the basis for a continuation in part currently being filed with the U.S. Patent office.

INTRODUCTION:

Current residential construction in the United States is based overwhelmingly on wood framing. This system is very efficient structurally and very economical to build. However, the system was developed before the advent of central heating and cooling. As a consequence, the system never had a provision for thermal air distribution. The "patch" to the system has been to run ducts through unconditioned attics and crawlspaces, where 30 to 40% of the energy can be lost before the air arrives at the conditioned space. These losses could be eliminated by bring the air distribution ducts internal to the thermal envelope of the residence. Typical commercial methods for dealing with this problem, such as hiding the ducts above a hung ceiling, have not proven to be aesthetically acceptable in the residential market. This project is directed at developing a product that will be aesthetically compatible with residential visual standards, while keeping the ducts internal to the conditioned space.

PROJECT ACCOMPLISHMENTS AND STATUS (ON A TASK-BY-TASK BASIS):

In the following narrative:

Each task in the contract statement of work is stated in **bold** text, followed by an explanation of progress on, and the status of, that task in normal text.

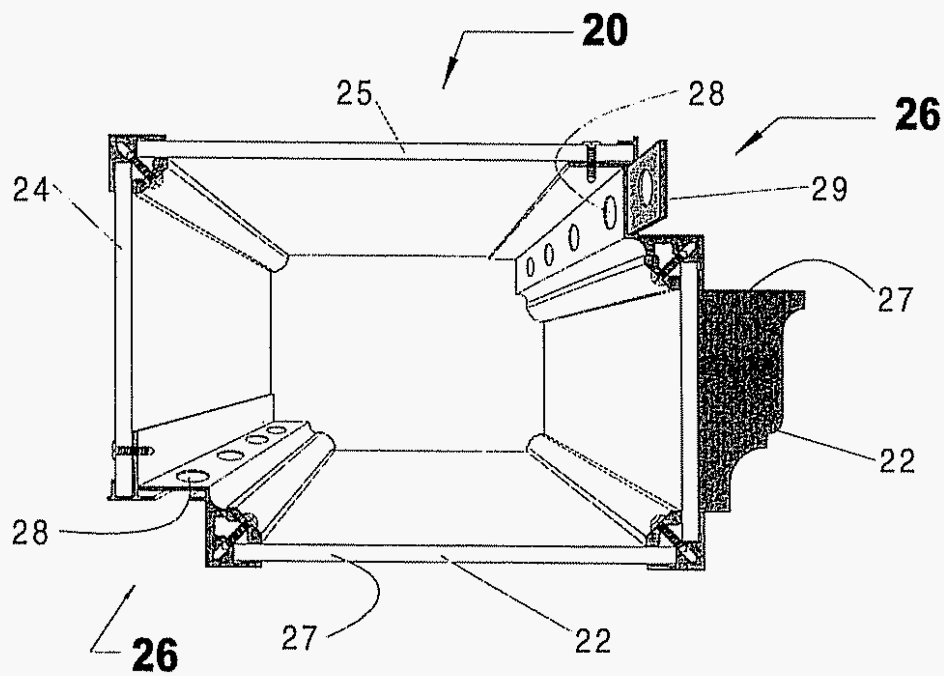
Task 2.1 – Component Fabrication

Based on the design and manufacturing techniques developed in Budget Period 1, the Recipient shall fabricate all full-scale prototype components necessary for installation of a complete Cornice Duct System in the Laboratory House.

Several means of fabrication were considered, including rolling aluminum sheet using a rolling system similar to that used to fabricate rain gutters. Gutter sections were made for the earliest testing in the previous phase of this project. Those sections had surfaces that oil-canned and their corners were very rounded, making it visually obvious that they were cheaply constructed of thin sheet metal. Various surveys indicated that the market response would be poor.

The system settled upon for the first major fabrication consisted of aluminum extrusions to form the corners and the detailed parts associated with the flow control. The flat walls of the duct were formed using fiber reinforced polyester sheet. (We originally experimented with PVC sheet, but all the samples that we tested burned furiously and out-gassed prodigious amount of foul smelling chemicals.) The aluminum extrusions made the corners rigid and also provided sharp edges that gave an appearance of higher quality than was the case for the rolled aluminum rain gutters.

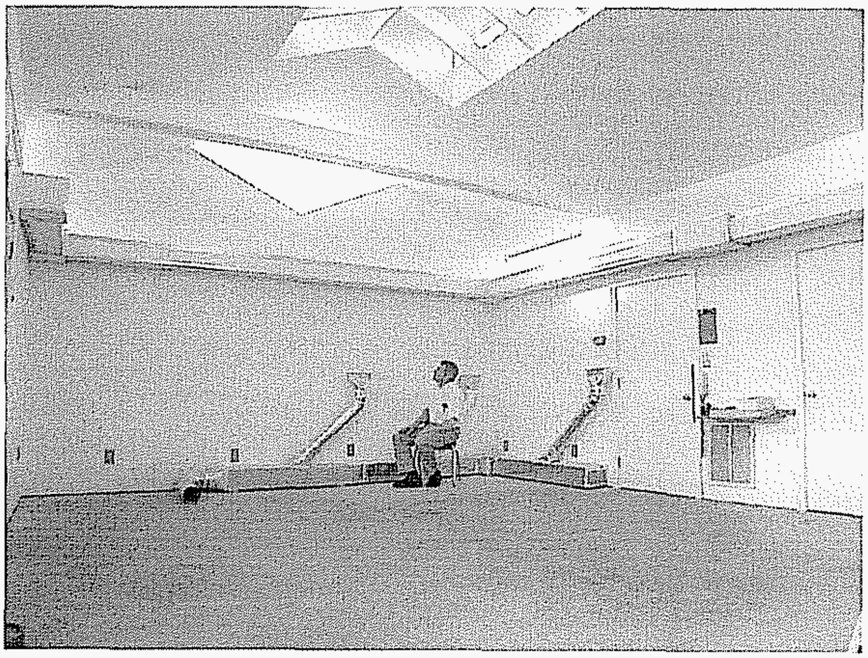
In this scheme, the duct was rectangular in cross section and the front face was added as a decorative element which presumably could come in a variety of profiles.



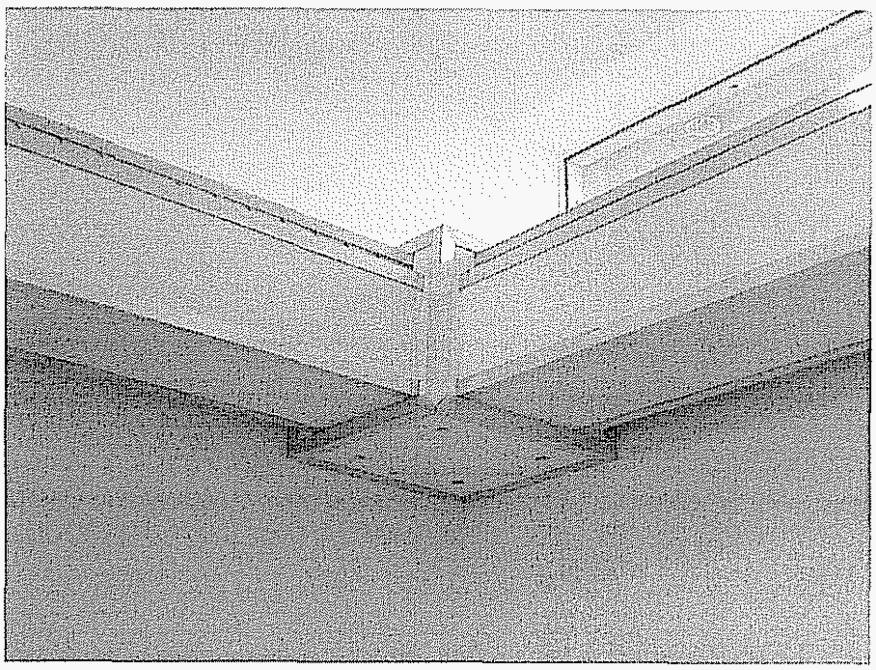
Legend for drawing above:

26—Recess to obscure the openings
28—Punched orifices to project air across the ceiling or down the wall
29—Sliding mechanism for controlling flow through orifices
22, 24, & 25—Walls of duct, made of glass fiber reinforced polyester
27—Decorative profile for face of duct

The first installation and testing of this duct design was at the Daylighting Facility at North Carolina State University, shown in the following photograph:



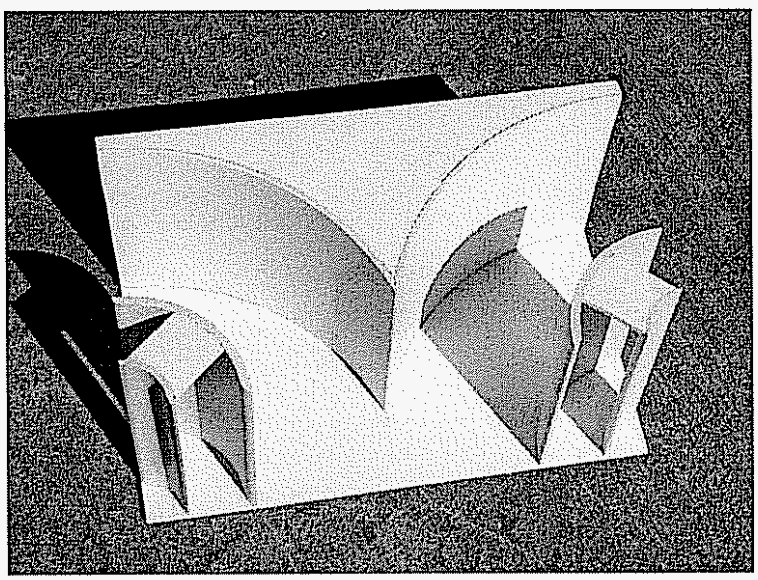
The next image shows a close up of the duct and one of the corner junction boxes:



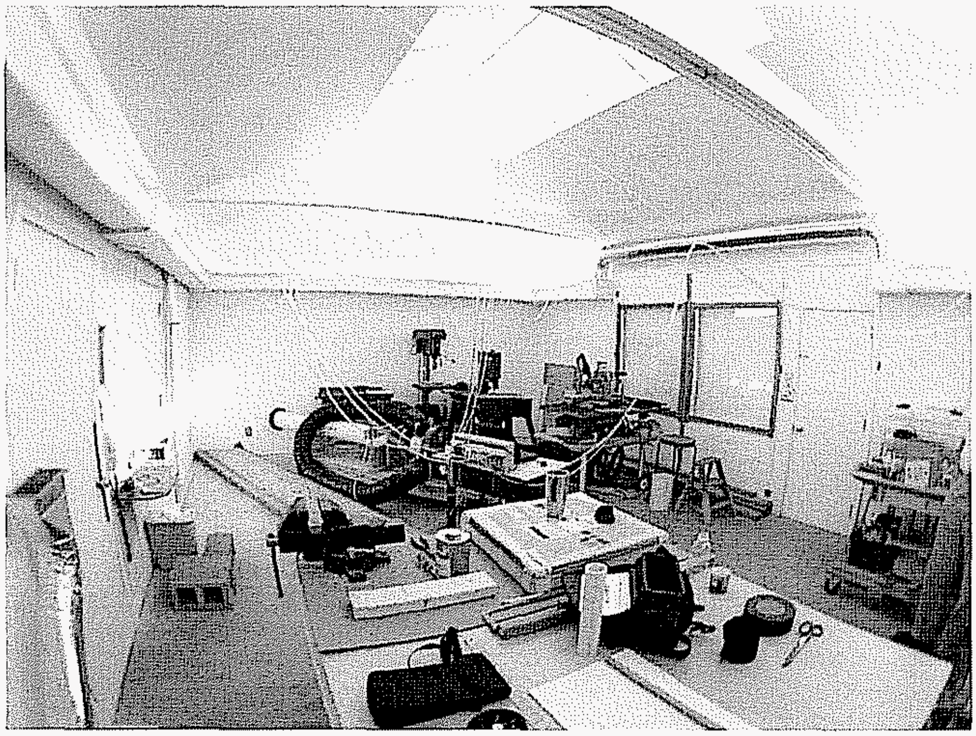
Barely visible at the top of the duct are the round holes through which air is expelled. These holes are set back to help obscure them visually. The decorative face piece was never added to this particular installation. The face piece was designed to help obscure the view of the openings from most parts of the room and also to provide a pleasing profile to the duct. Since the installation in this building was for testing air flow and was never intended for visual evaluation, the face piece was never installed. In the photograph above, the sliding mechanism was adjusted to seal the holes at the top of the duct. In this testing mode, the holes were open at the recess at the back, lower corner of the device. That is, it was configured to project hot air down the wall, rather than across the room. This image also shows a corner junction box, which was the means of support for the duct. In this scheme, the duct was inserted into, and spanned between, the corner junction boxes. For duct runs over about 15 feet, a center support was required to avoid excessive deflection and stress in the tubular duct.

The following image shows the junction box where the air handling system injected air into the duct:

The next photo shows the interior veins for redirecting air at this junction box:



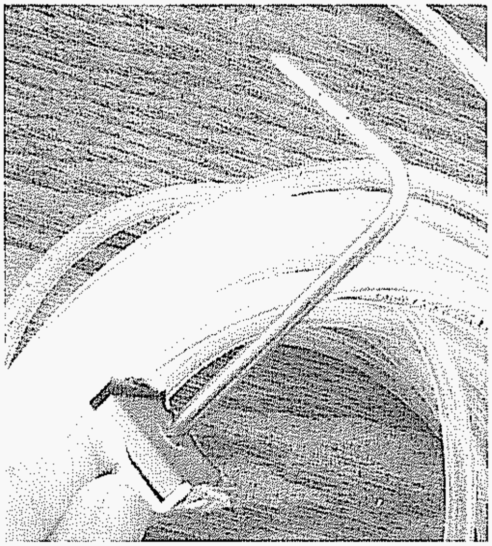
In this configuration, the air flow was split, directing half the air into a duct running around the west side of the space and half the air into a duct running around the east side of the space. It was rapidly ascertained that the duct cross-sectional dimensions of 8" x 10" was more than ample to supply air over these runs of duct. To push the limits of the duct cross section, it was decided to direct the flow only to the west and to provide a path for circulating the air around the entire space. This required adding a section of duct over the large service door, to jump the gap from the west side to the east side (see shiny round duct in the next image):



This allowed run of 84 feet around the entire space. Tests on this configuration indicated a remarkably consistent flow velocity out of the orifices in all parts of the space. There were, however, indications of thermal degradation, in that the temperature of the air ejected out of the orifices at the end of the 84-ft run was not as warm as the air ejected out of the orifices near the air handling unit. This issue will be addressed later in the discussion of the test results from the laboratory house. The installation in the Daylighting Facility provided useful experience regarding the fabrication process and also provided data that assisted in sizing the ducts for the Laboratory House.

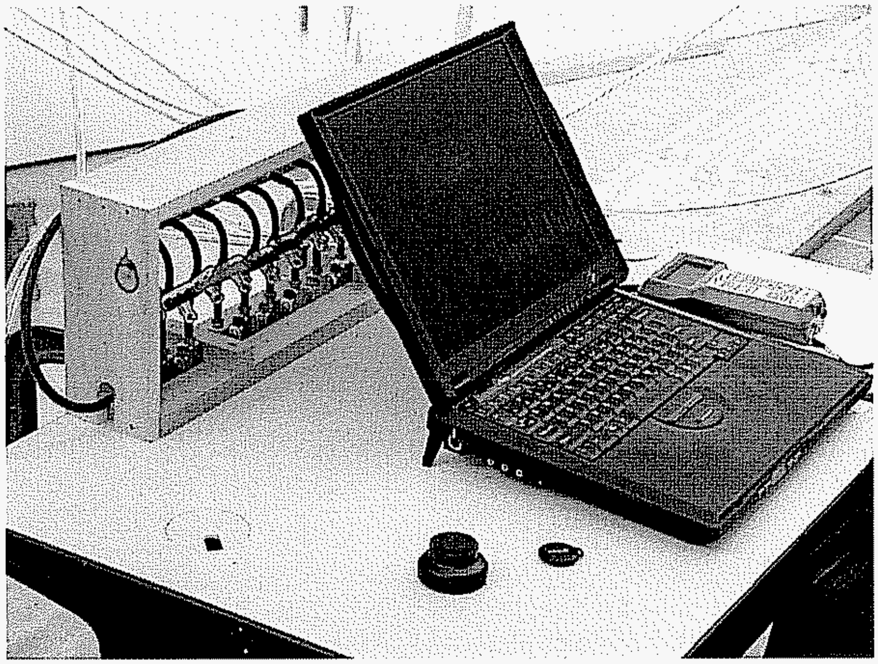
Pitot meters were mounted in side the duct at various points along the length of the duct to measure flow along the the duct. Each meter was connected by a plastic tube back to a central point where they could be sampled by the manometer. These plastic tubes are visible in the photo above.

The following is an image of one of the Pitot Tubes:

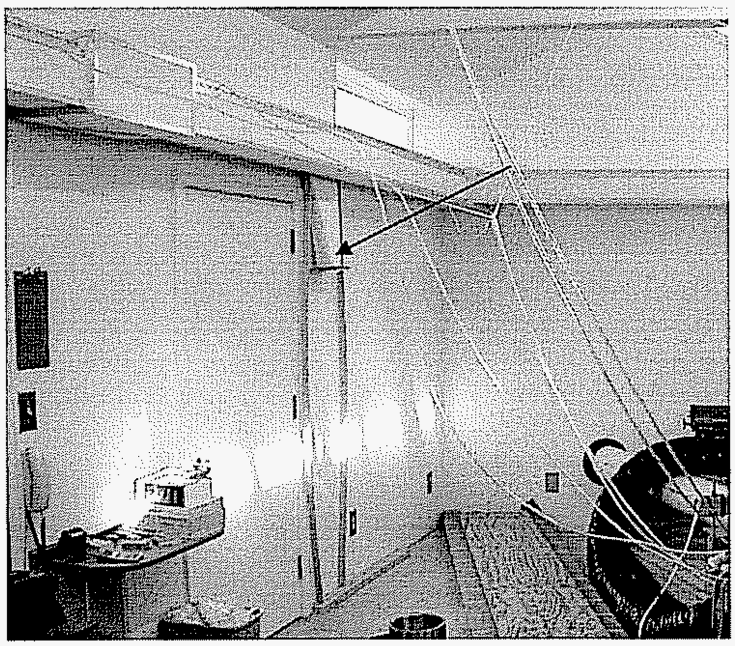


The following is an image of the Dwyer Instruments 475 Mark III Digital manometer that was used in conjunction with the Pitot Tubes:

The following is a close-up of the tubes running from the Pitot Tubes. Clamps were used to constrict the elastic tubes for switching between the Pitot Tubes being sampled by the manometer. Data was recorded on the laptop computer. Also shown in the photo is another manometer used in the experiment.



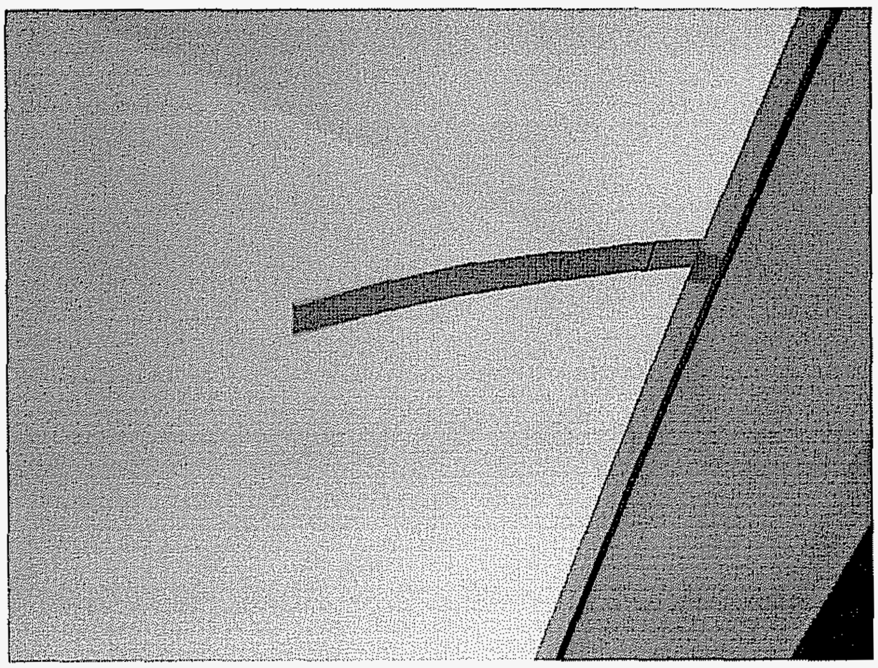
Air flow out of the orifices was measured using a cowling that was shaped to form a long slot on one end (to sample from several of the round orifices lined up in a row) and shaped to be round on the other end to accommodate the Alnor model RVA rotational vane anemometer. This cowling is shown to the left in the following image:



The bowed sticks are used to press the end flange of the cowling up against the extrusion with the punched holes in it.

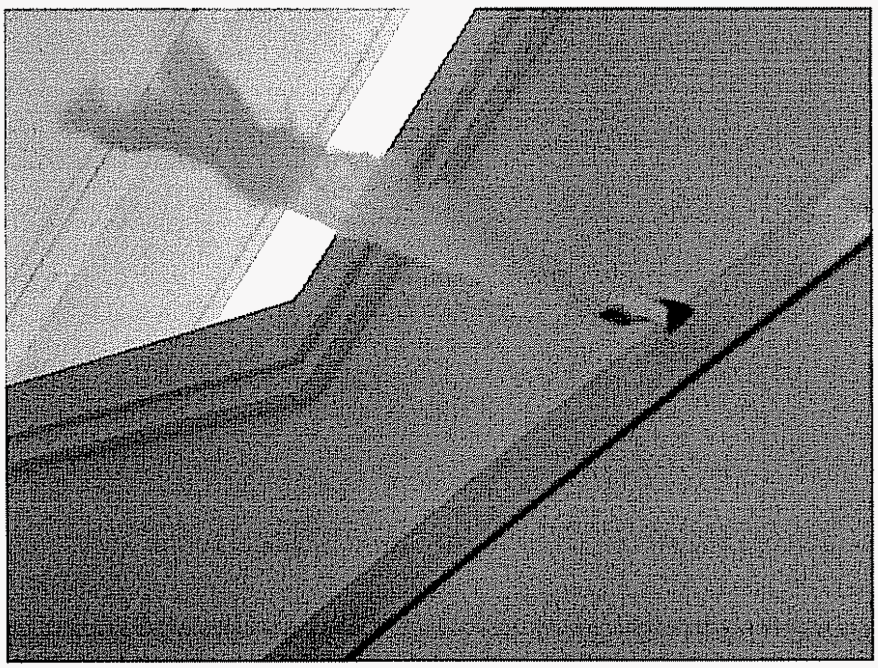
The following image shows the Alnor model RVA rotation vane anemometer that would be used on the bottom end of the cowling above. In this photograph, the anemometer is shown being used to measure air flow at the return air filter.

Streamers of paper and tissue paper were also used as indictors of air flow rate out of the orifices that project air across the space. These provided immediate visual evidence of how the air was coming out of the orifices all around the space. The next photo shows a paper streamer at the end of the 84-ft run with the only open orifices being those projecting air across the space:



Without the air flow, the paper streamer would be dangling close to vertical down the face of the duct. The high flow rate near the end of the 84-ft run was attributed to dynamic pressure associated with the air stream inside the duct colliding with the end wall of the duct. The next photograph shows a streamer at a different location on the duct, with all the orifices open; i.e., both the orifices projecting air across the space and the orifices projecting air down the wall. This streamer is drooping more than in the image above, because the flow through the top orifices is being sapped by flow through the orifices directing air down the wall.

The tissue paper provided even more dramatic visual indications of the air flow:



Task 2.2 - System Installation in Laboratory House

The Recipient shall install a complete Cornice Duct System and related HVAC equipment in the laboratory house. The layout of the Cornice Duct System shall allow the system to be tested under different configurations, including 1) Duct runs around the perimeters of the house, and 2) a more centralized configuration that minimizes overall duct length. The Recipient shall balance the system for each test configuration to insure that the air distribution conforms to the design dictates. The recipient shall install test instrumentation in the laboratory house to carry out the testing protocol developed in budget period 1. Instrumentation shall include, but not be limited to:

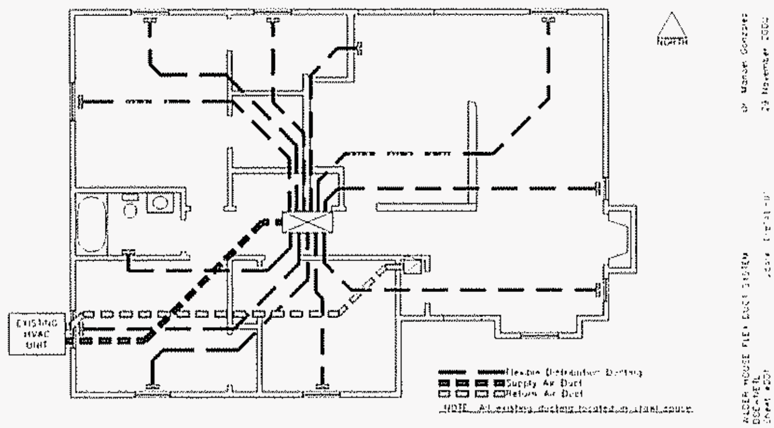
- **Instruments for each room in the laboratory house to acquire air distribution, temperature, and acoustic data.**
- **Instrumentation of the heat pump and air handling fans to acquire electricity consumption data.**
- **Installation of exterior weather data acquisition sensors to monitor temperature, humidity, and wind velocity at periodic intervals.**

The laboratory house shall be equipped with an instrumented, conventional-duct HVAC system to allow comparison with the Cornice Duct System.

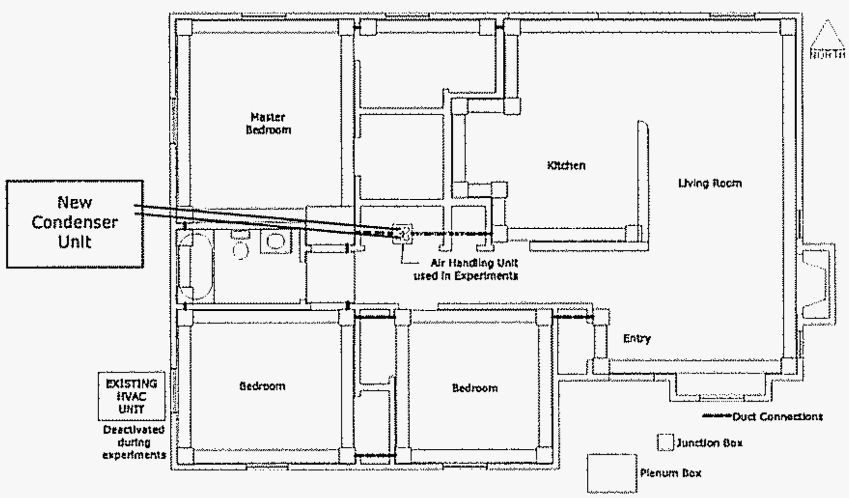
The recipient shall conduct all check-out, calibration, shake down, and related activities necessary to prepare for testing performed under Task 2.3.

The following photograph shows the laboratory house on Wilder Street in Raleigh, NC. Synergetics bought this house as part of their cost-sharing on this project.

The next image shows the floor plan and the initial installation of flexi-duct in the crawlspace of the house:

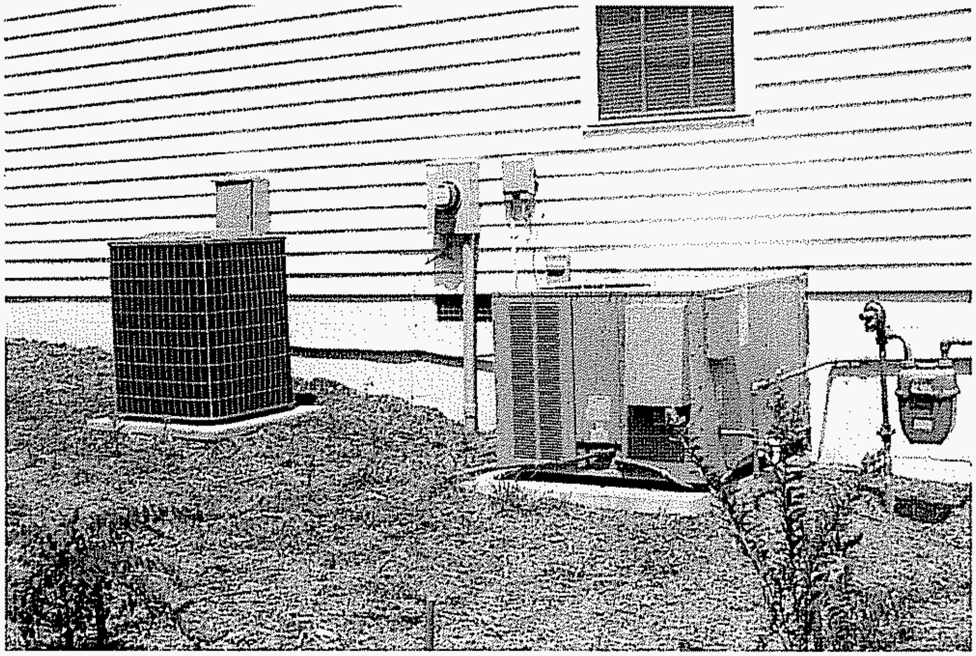


The next image shows the experimental layout of Cornice Duct:

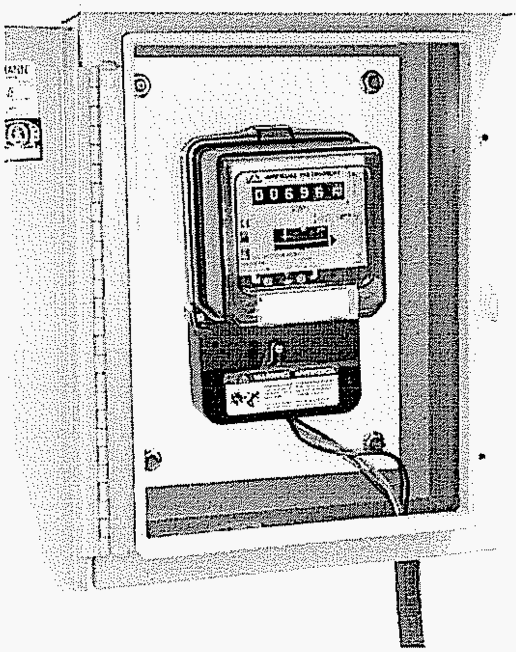


In the experiments, the existing HVAC unit that came with the laboratory house was deactivated and a new heat pump was added. The air handling unit of the new heat pump system was located in a central closet. The laboratory house was operated alternately on the Cornice Duct system and the existing flexi-duct network in the crawlspace by using dampers to redirect air from one system of ducts to the other. This arrangement used the same central plant in testing both duct systems, thereby assuring that the comparison was from one duct system to the other, without other elements in the system changing.

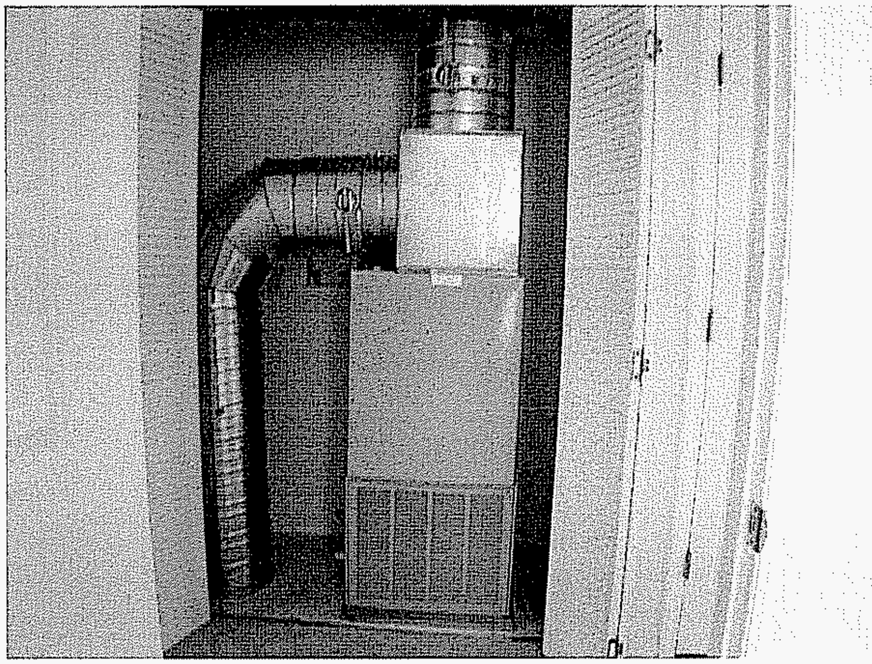
The following photo shows the original HVAC system (to the right) and the new condenser unit (to the left).



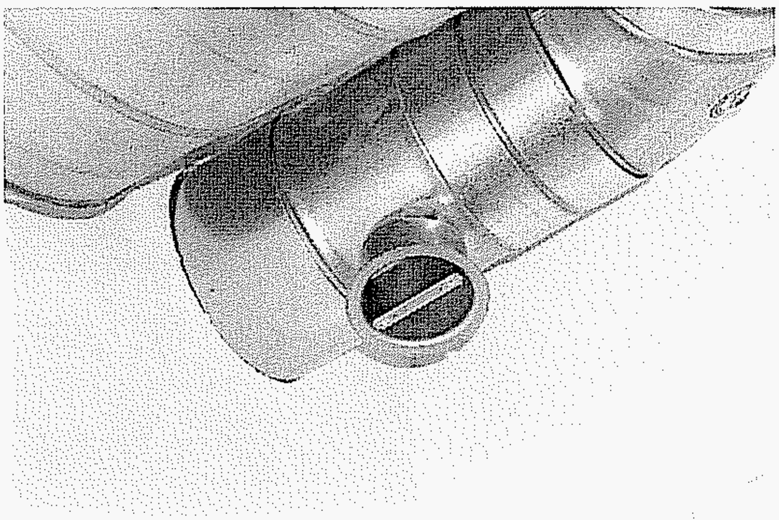
The next photo shows the Amprobe model #WH2VIA1P3W kilowatt-hour meter used to measure electricity consumption by the new condenser unit:



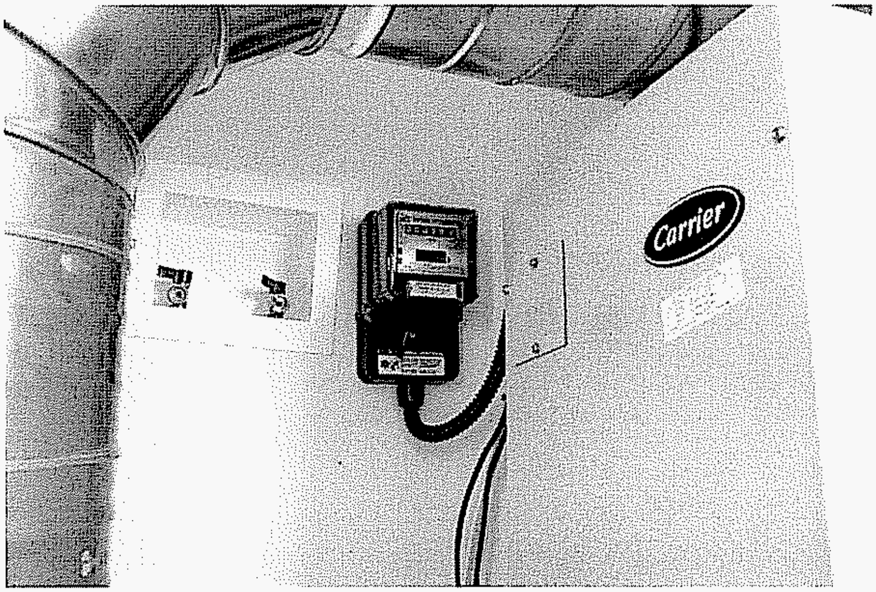
The following image shows the air handling unit in the interior closet, with the damper above for opening and closing air flow to the Cornice Ducts and the damper to the left for opening and closing air flow to the flexi-ducts in the crawlspace:



Additional dampers were included in parts of the network to adjust flow to the duct and to fine-tune the experimental arrangement. The next photo shows such a damper for throttling air flow to the Master Bedroom:

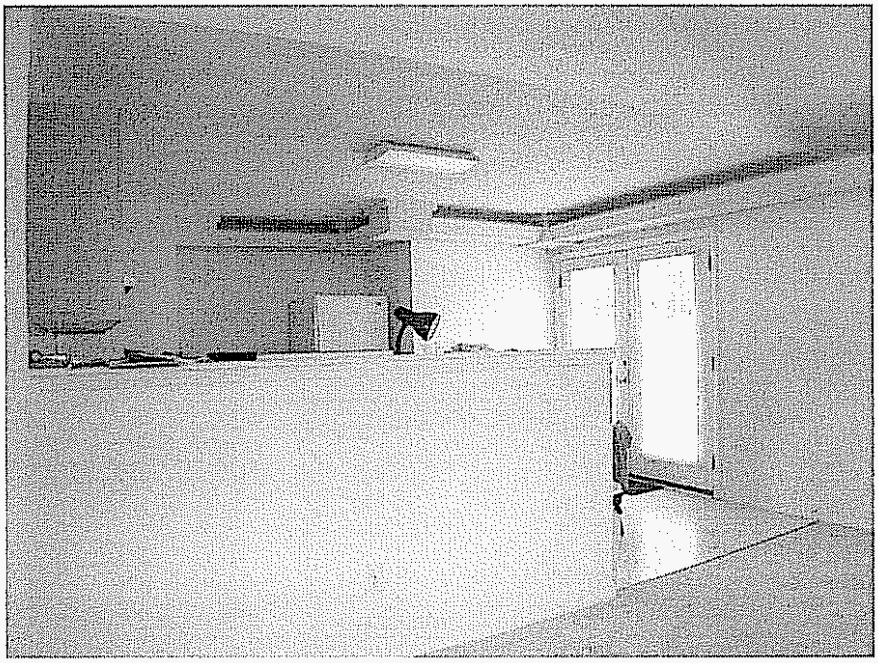


The next image shows the Amprobe model #WH2VIA1P3W kilowatt-hour meter used to measure consumption of electricity by the fan in the air-handling unit:

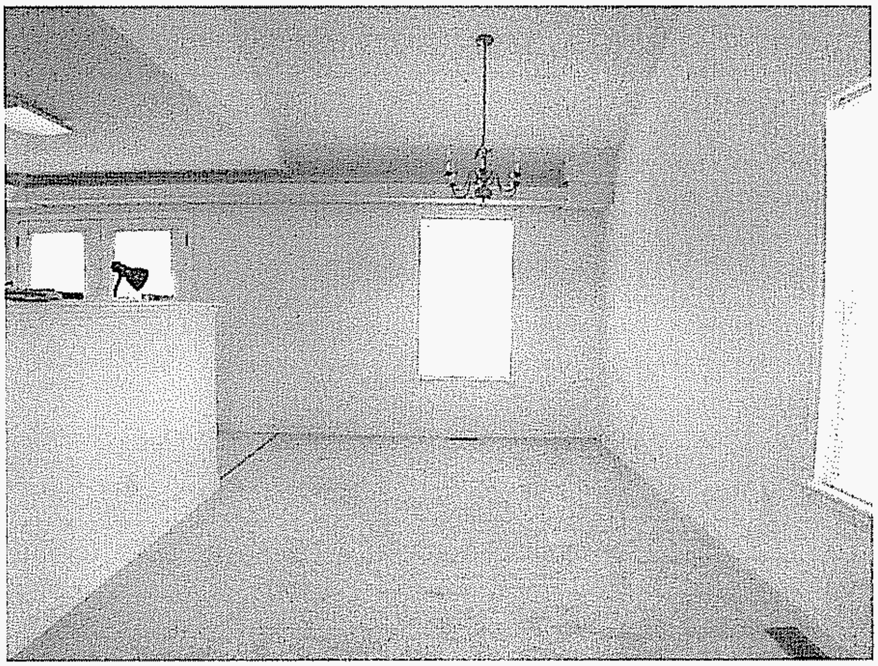


The next image shows a close-up view of the cornice duct in the laboratory house:

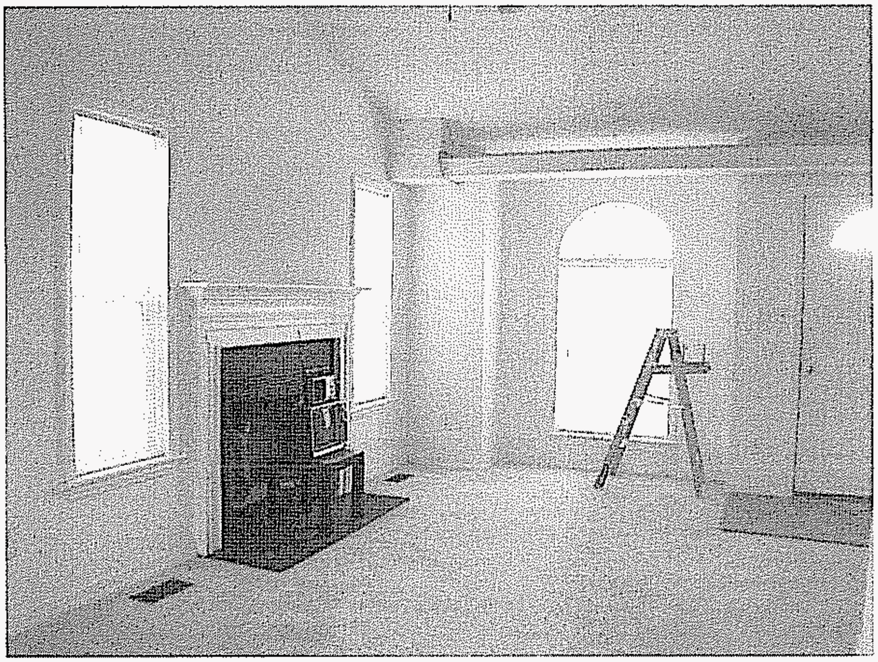
The cornice duct in the kitchen (as seen from the living/dining area):



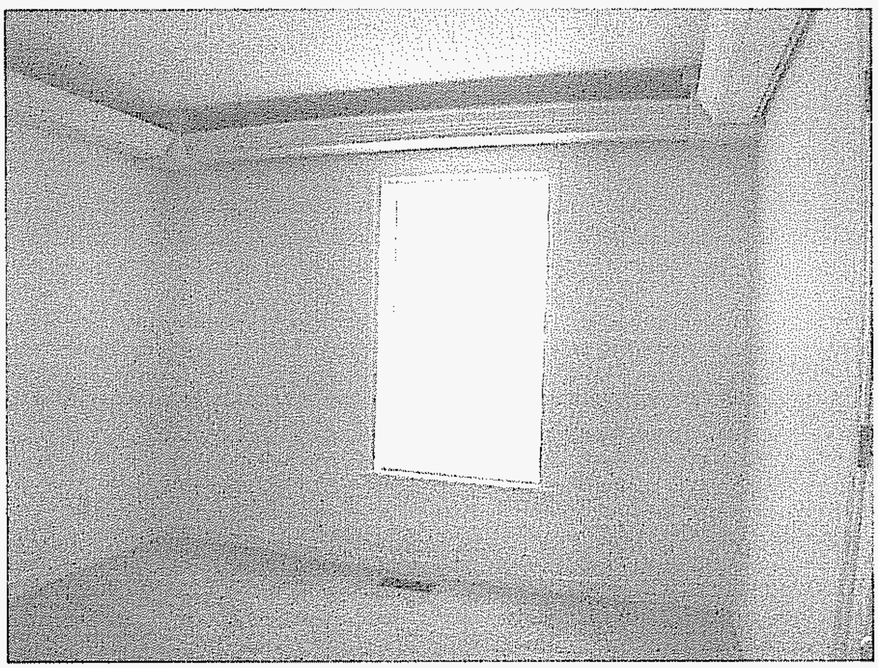
The cornice duct on the north wall of the living/dining area:



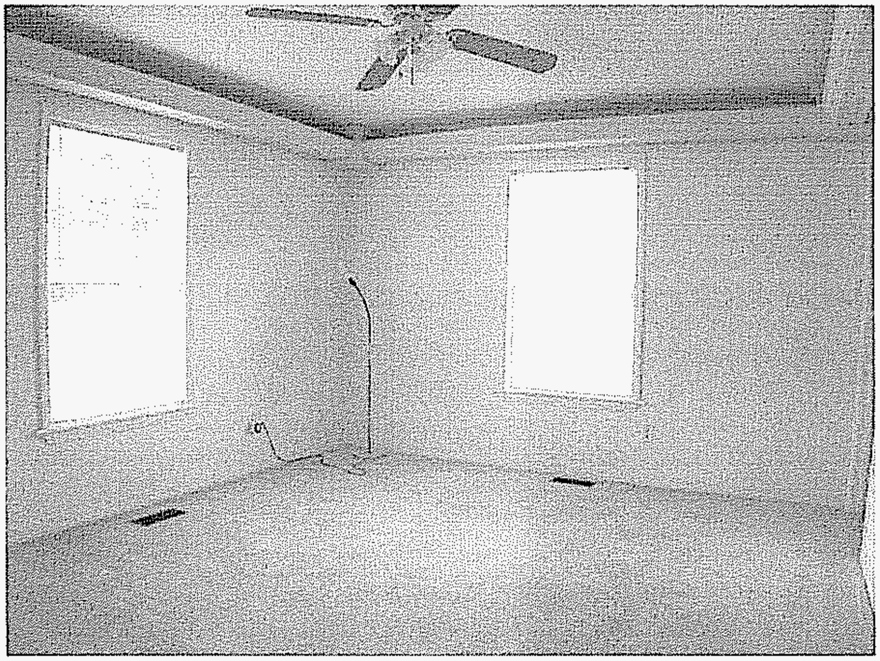
The cornice duct on the south wall of the living/dining area:



One of the lesser bedrooms:

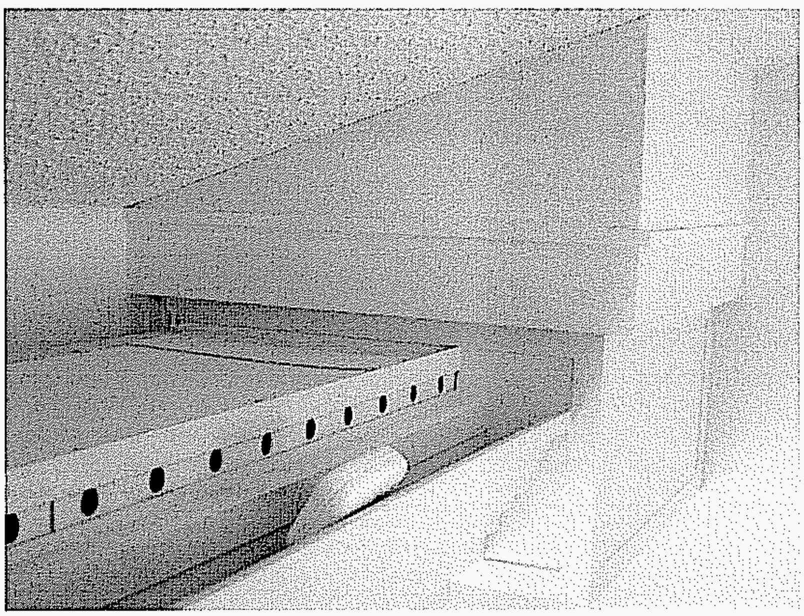


The master bedroom:



Cornice duct was installed to service all areas of the house, including the bathrooms, although we suspect that simple diffusers mounted in the wall make more sense than the Cornice Duct for small, humid spaces such as bathrooms. (See Design Guidelines attached.)

Temperature and humidity were monitored using Dickson Model TX-120 temperature and humidity meter/loggers. In the following photograph, Dickson Model SX-100 temperature meter/loggers were mounted in front of the orifices at various points along the ducts to measure the temperature of the air emitted through the orifices:



The same temperature measurement devices were hung at various locations in the spaces to determine the temperature distributions within the occupied spaces.

Task 2.3 – Full-Scale Prototype System Testing

The Recipient shall conduct testing of the laboratory house HVAC systems that incorporate the conventional duct system and the Cornice Duct System in accordance with the approved testing protocol developed in Task 1.4.

Insert stuff from most recent file from Chuck

Experiments

The following is a brief summary of the experiments that have been performed at the test house.

Introduction

Several key observations were made in the house:

1. *As predicted based on the previous experiments, substantial amounts of air are being delivered to all parts of the network in the test house.*

2. *Delivering air on multiple sides of a room appears to be counterproductive, creating a tendency for conditioned air to collide at the center of the room. When the air is being delivered horizontally across the ceiling (from the openings at the front/top of the Cornice Ducts), the air collides at the center of the room and then descends on the heads of the occupants. In contrast, air delivery on one side appears to be smoother and more effective, leading to a greater level of human comfort.*

3. *The surfaces of the ducts are fairly warm in the vicinity of the heat pump, indicating that a fair amount of the heat is conducting through the walls of the duct and is being delivered to the space by radiant and convective transfer from the surfaces of the ducts. This suggests the desirability of minimizing the length of duct runs. Of course, minimizing duct runs also has economic advantages.*

4. *At the ends of duct runs, the heat degradation is apparent, with air being delivered at a perceptibly reduced temperature. This effect is most pronounced at the ends of the long runs, but it is even observable within a single room when the conditioned air is being delivered to the room by the duct on the outside wall of the room. Again, this suggests the desirability of minimizing the length of duct runs.*

Items 2, 3, and 4 above were addressed by limiting the output flow of the cornice duct system to only one wall for each room. The flow pattern used for these experiments is shown in the following drawing.

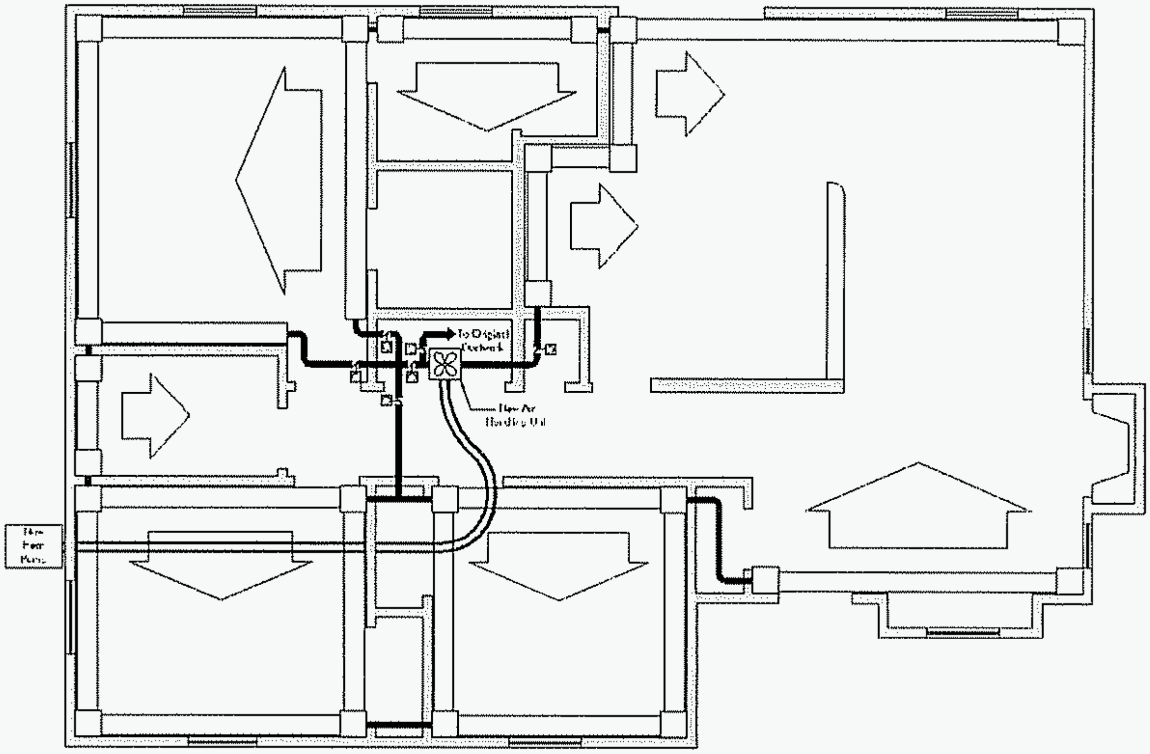


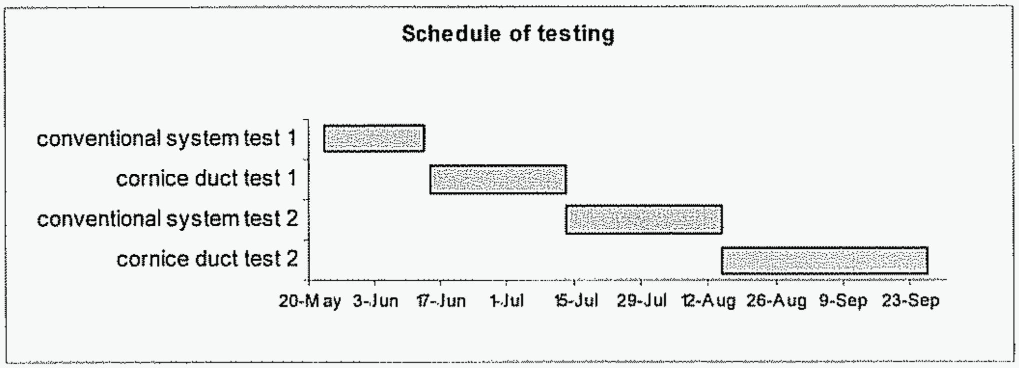
Figure 1 - cornice duct flow arrangement

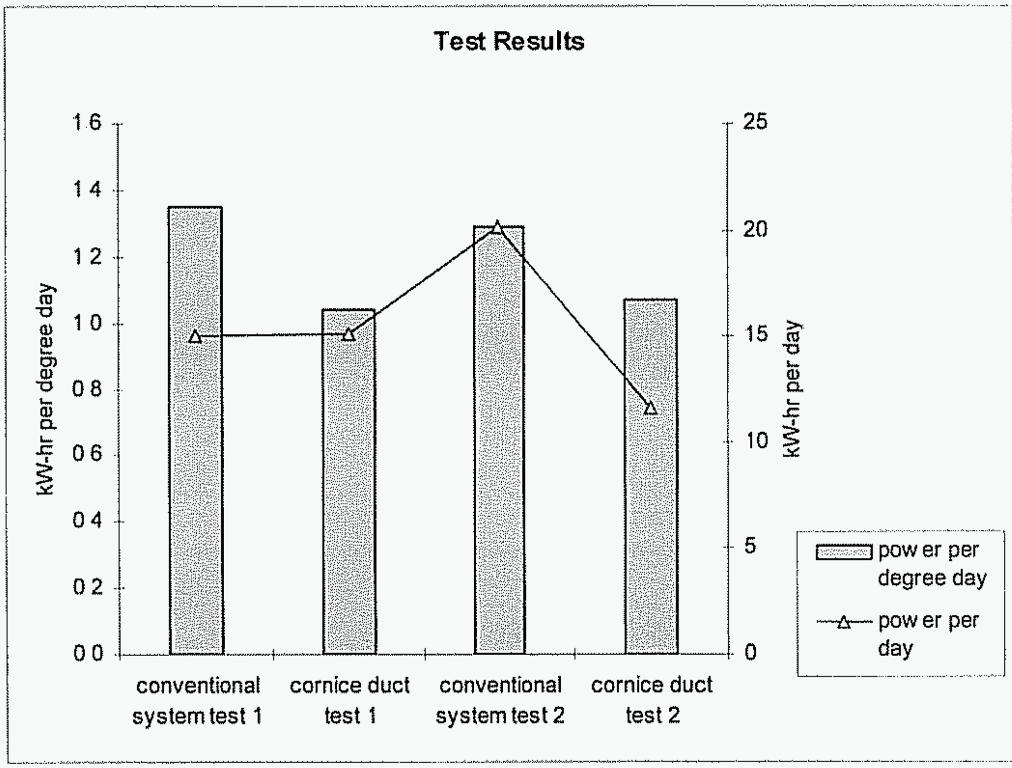
Power measurement testing

Power measurement testing involved alternately operating the conventional and cornice duct systems at a set temperature while measuring the environmental conditions both inside and outside the test house. Power consumption was measured using kilowatt-hour meters installed on the HVAC compressor and fan (one meter each) and verified using the utility installed kilowatt-hour meter. Environmental conditions were measured inside the test house using the standard HVAC thermostat, with local temperature and humidity sensors, and with air velocity meters. Environmental data for external conditions was collected from the National Weather Service (WS Form F-6, local climatological data from the Raleigh-Durham Intl. Airport) and from the NC State Solar Center, which is less than half a mile from the laboratory house. Cooling system power consumption data was collected from 23 April 2002 until 26 September 2002 and has been completed.

The cooling system power consumption tests are summarized in the charts on the next page. The power use for these tests was compared to the degree-days of cooling for the testing period. These comparisons show a substantial and consistent energy savings for the cornice duct system versus the conventional ducting. The energy use per day for the tests has been included but this data varies based on external environmental conditions during the test and is therefore not an indication of the relative efficiencies of the two systems.

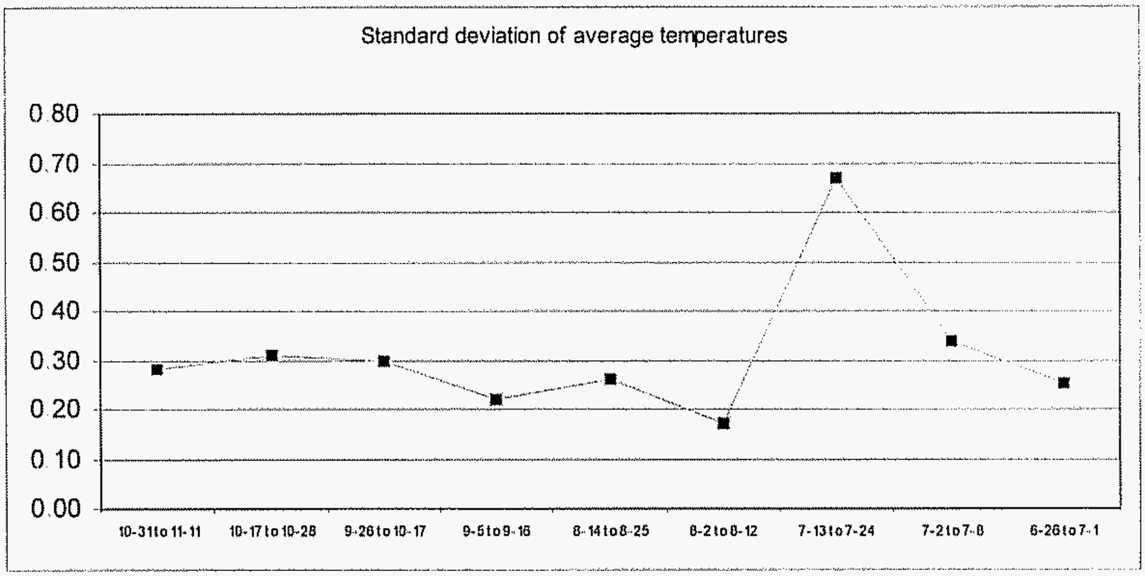
Note: Cooling degree-days are notorious for being skewed by solar gains and internal heat sources in the building. However, the impact of these factors was kept to a minimum, because we have a laboratory house with no occupants to generate internal heat loading and because windows were kept fairly well shaded to avoid large inputs of solar heat. Therefore, normalizing the data based on cooling degree-days can be argued to have validity in this experimental situation.


Schedule of testing
conventional system test 1
cornice duct test 1
conventional system test 2
cornice duct test 2
20-May 3-Jun 17-Jun 1-Jul 15-Jul 29-Jul 12-Aug 26-Aug 9-Sep 23-Sep


Test Results
kW-hr per degree day
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
kW-hr per day
25
20
15
10
5
0
conventional system test 1
cornice duct test 1
conventional system test 2
cornice duct test 2
power per degree day
power per day

Room temperature testing

The temperature was measured in various locations in a single room in the test house during the cooling season. The results of the completed tests are summarized in the chart below. The variance of temperature between sensors in the test room never exceeded 1 degree F (the sensors are accurate to ± 0.1 degree F). A variety of arrays of temperature sensors were used. The highest standard deviations of temperatures were observed during the two tests where the sensors were distributed at different heights in the room (the tests starting on 2 July and 13 July). In these tests, as expected, the highest reading sensor (T02) was located physically higher than the other three sensors.



Air velocity measurements

Air velocity was measured using a handheld air velocity meter. Conventional system air velocity measurements were taken at each register and at the return air intake. Air velocity measurements for the cornice duct system were taken at the return air register for comparison with the conventional system. Measurements were also taken at the outlets of the cornice ducts and qualitatively assessed to be satisfactory. The air velocity data indicates a consistent quantity of air is delivered for both systems to all rooms in the test house. It was also observed that the difference in sensed air velocities across the spaces was lower with the cornice duct system than with the conventional system.

List of test instrumentation

Power:	Amprobe model # WH2VIA1P3W kilowatt-hour meters
Pressure:	Pitot tubes
Pressure:	Dwyer Instruments 475 Mark III Digital Manometer
Pressure:	TSI Model 8705 DP-CALC Micromanometer
Air velocity:	Alnor model RVA rotation vane anemometer Bacharach Flo-Rite air velocity meter
Temperature:	Dickson Model TX-120 temperature and humidity meter/logger Dickson Model SX-100 temperature meter/loggers

Task 2.4 – Computer Modeling.

The Recipient shall conduct Computational Fluid Dynamic modeling of the room air distribution provided by the Cornice Duct System in each configuration tested in the laboratory house (e.g., perimeter supply and central supply). Modeling of the room air distribution provided by the conventional duct system (e.g., grills and diffusers) shall also be conducted. This modeling is intended to yield graphical depictions of the air velocity and temperature distributions produced by the Cornice Duct and conventional duct systems for comparison. Modeling shall be conducted for at least two rooms of the laboratory house. Modeling of the air flow within specific components of the cornice duct system (e.g., at a corner) shall also be conducted.

After extensive investigation and assessment, the Recipient did not believe that this task would be the most productive approach to advancing understanding of this system. Rather, it was believed that more rapid and economical insights can be generated by expanding the experiment studies. This opinion has been reinforced in conversations with John Van Osdal of NETL.

Of far greater concern to the Recipient is fabricating and testing recent design advances that have emerged from the experimental tests and from the experience of fabricating the ducts for the laboratory house.

Recipient requested that the $45K originally allocated for software acquisition for Task 2.4 - Computer Modeling be made available for fabricating, installing, and testing advanced versions of the Cornice Duct that emerged out of the experience of installing and testing the original system in the Laboratory House. This request was made to Kelly MacDonald and William Haslebacher and they gave written approval, conditional on the fact that it will be a no-cost revision to the contract. The overwhelming majority of that money (approximately $40K) was spent on die costs and extruded aluminum for new versions of the Cornice Duct. The remainder of the money was spent on labor for installation, experimental testing, and evaluation. That new work is described in the task starting on the next page.

Task 2.4B – New Task (to replace Computer Modeling): Developing a Second Set of Extrusions for the Cornice Duct

Many refinements were made to the original design of the Cornice Duct and those refinements were incorporated into the two final prototypes. These refinements are also being incorporated into the patent continuation in part. Among the changes made in the device are the following:

1. The openings for air were redesigned so that they are not visible to any persons anywhere in the occupied space, regardless of how far away from the ducts they are standing. This enhances the visual appearance of the product.

2. The openings for air were configured to enhance laminar flow across the ceiling, since this appeared to be the most promising method of achieving good thermal comfort and minimal system cost.

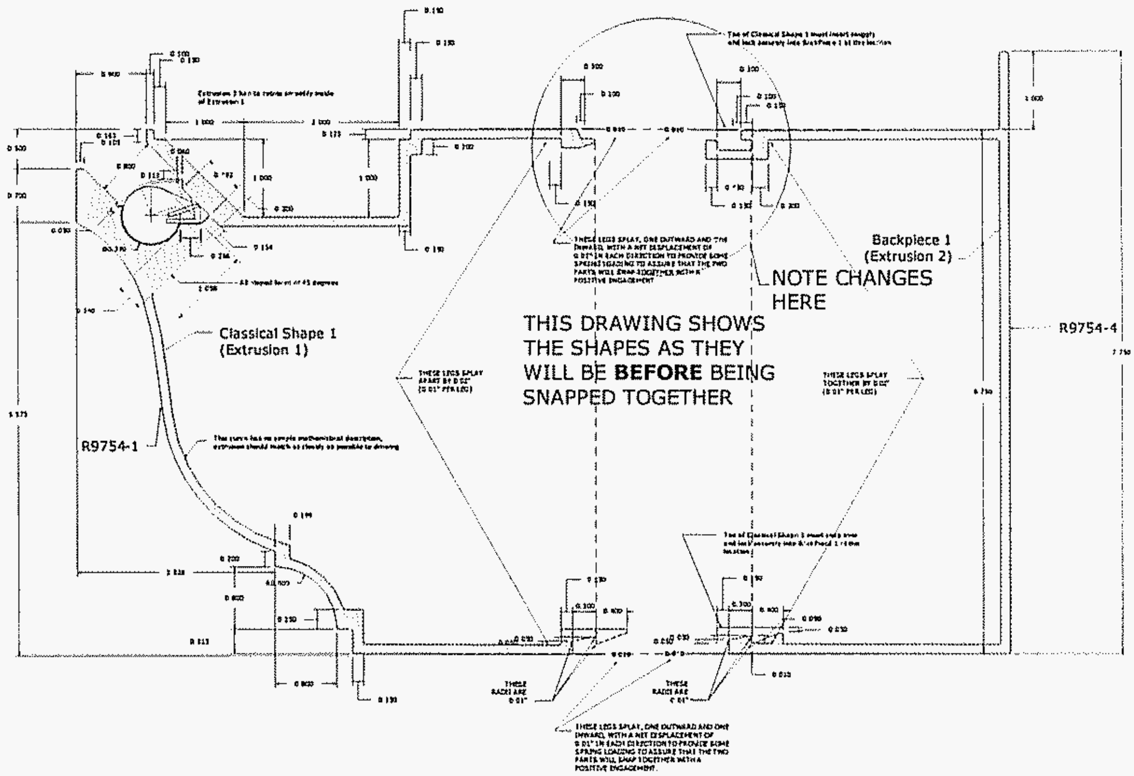
3. The controls for the openings were redesigned to eliminate the costly fabrication operation of punching and also to eliminate the high tolerances required to assure alignment of punched openings.

4. The design was simplified in terms of the number of parts and in terms of the procedures for assembly. These simplifications apply to both the ducts and the corner boxes.

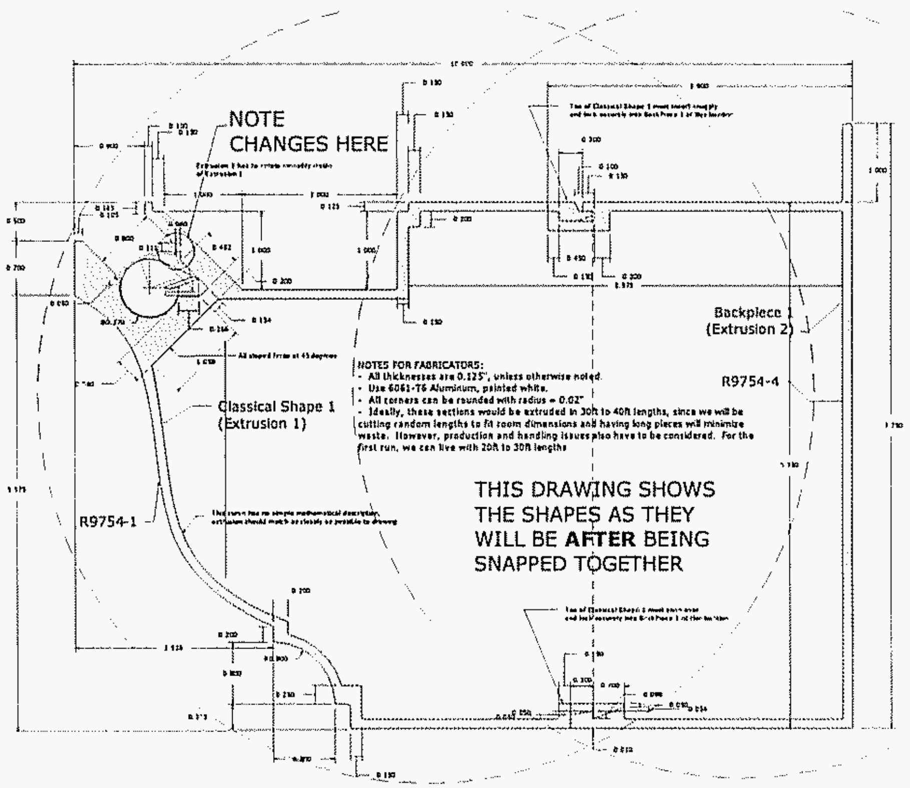
5. Concepts for lighting were incorporated into the Cornice Duct.

6. A version was generated that is strong enough to use as a shelf.
   For economy reasons, this device may most often be used on only one side of the room. In this arrangement, it will no longer be perceived as a cornice. In the light of that fact, the salability of the device may be enhanced by mounting the device lower on the wall and promoting it as a decorative shelf. Mounting it lower on the wall also enhances the performance of lighting incorporated into the device, since the light source will be further from the ceiling, thereby allowing more uniform distribution of light on the ceiling and reducing the severity of the angle of the light incident on the ceiling, which is problematical in terms of highlighting flaws in the ceiling. Making the duct strong enough to work as a shelf to support heavy loads, such as books or a person hanging on it, has alleviated the concern for liability for someone being hurt by pulling the duct down on top of themselves.

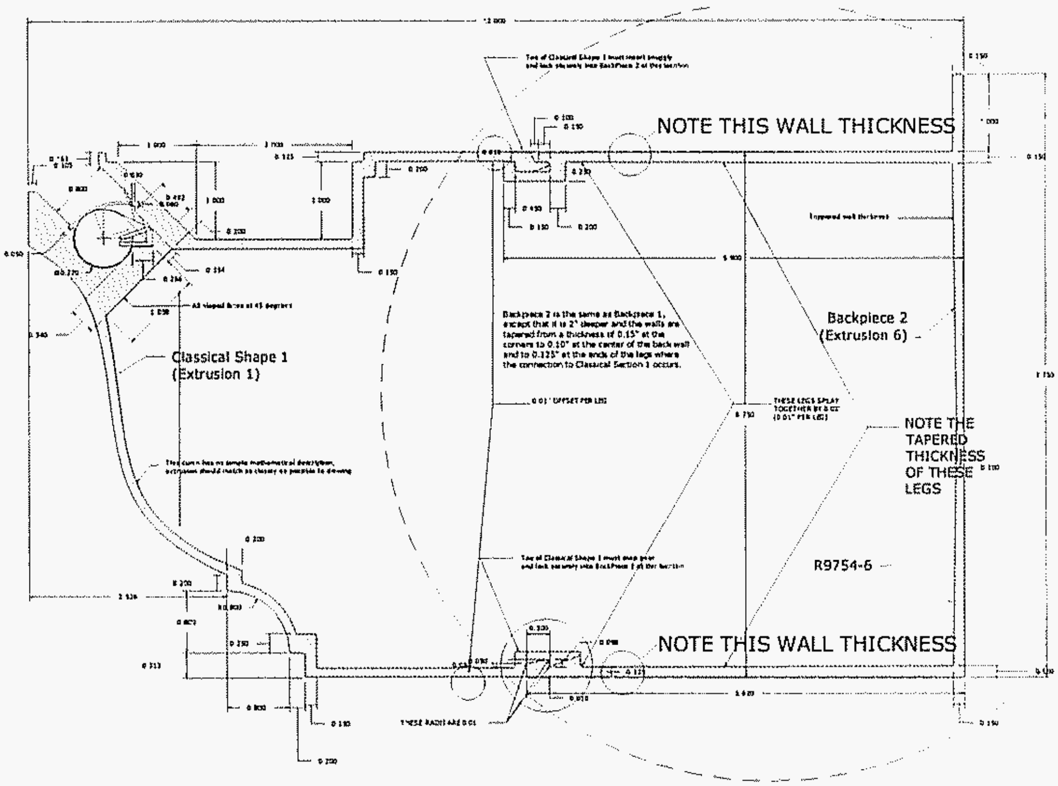
Dozens of variants were designed before a final design was selected for the second extrusion set. At several stages along the way, conversations were held with the engineer at the extruding mill to discuss issues about the viability/extrudability of the designs. The following images show the design that was chosen for extrusion set two. This extrusion is near the large end of the spectrum of sections that would ultimately be fabricated and sold. We chose to do the large version because it would be the most challenging in terms of having the extrusion hold its shape. The first image shows the front extrusion and the shallow back extrusion as separate elements:



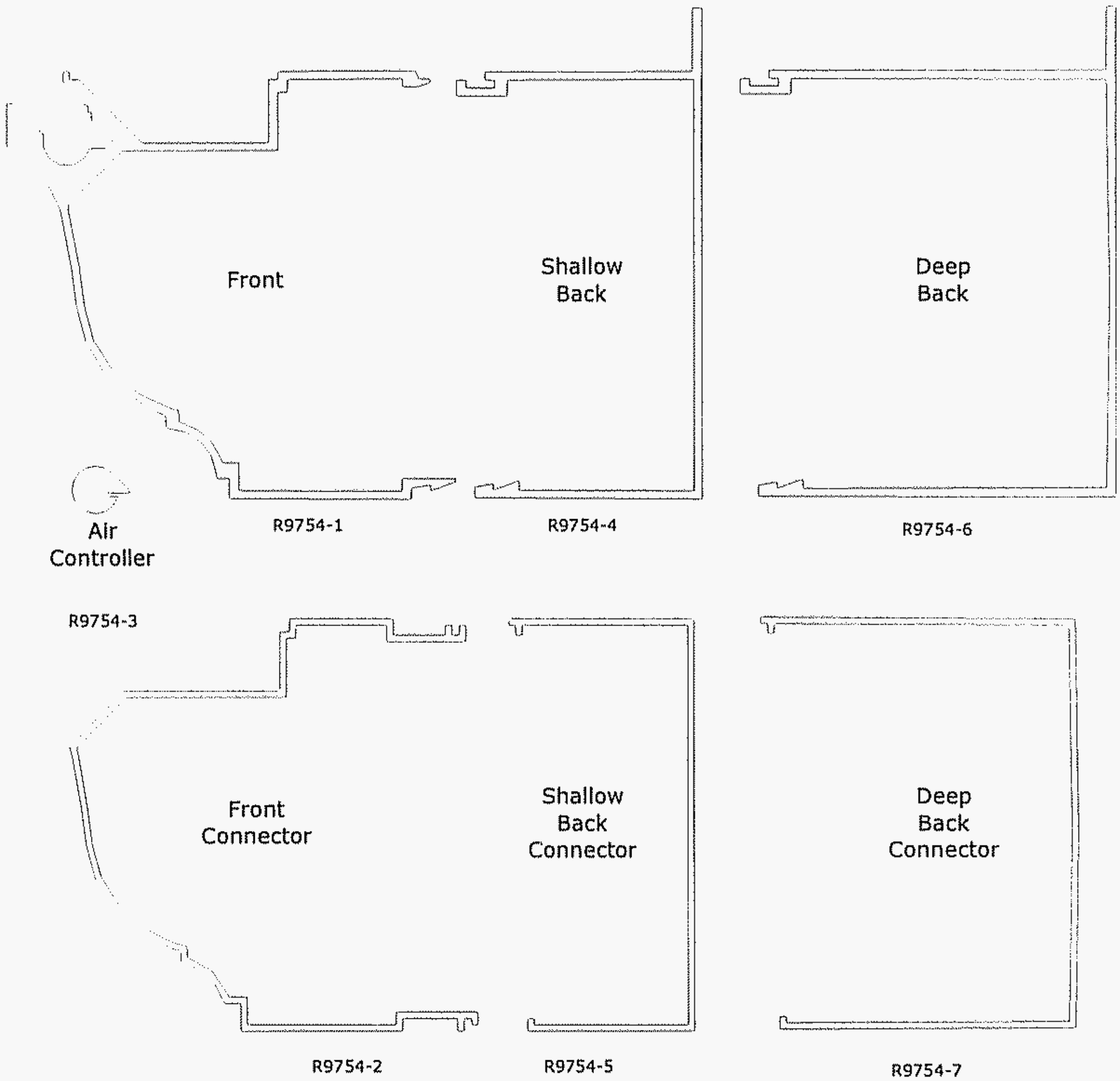
The next image shows the front extrusion and the shallow back extrusion snapped together to produce a closed tubular duct:



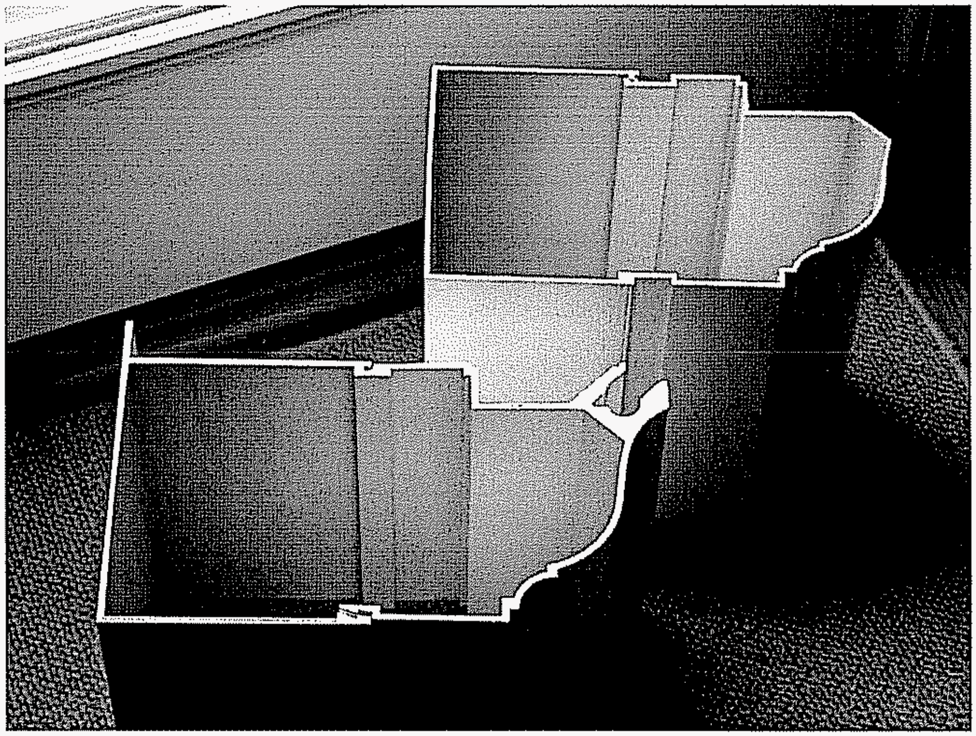
The next image shows the front extrusion snapped into the deep back extrusion:



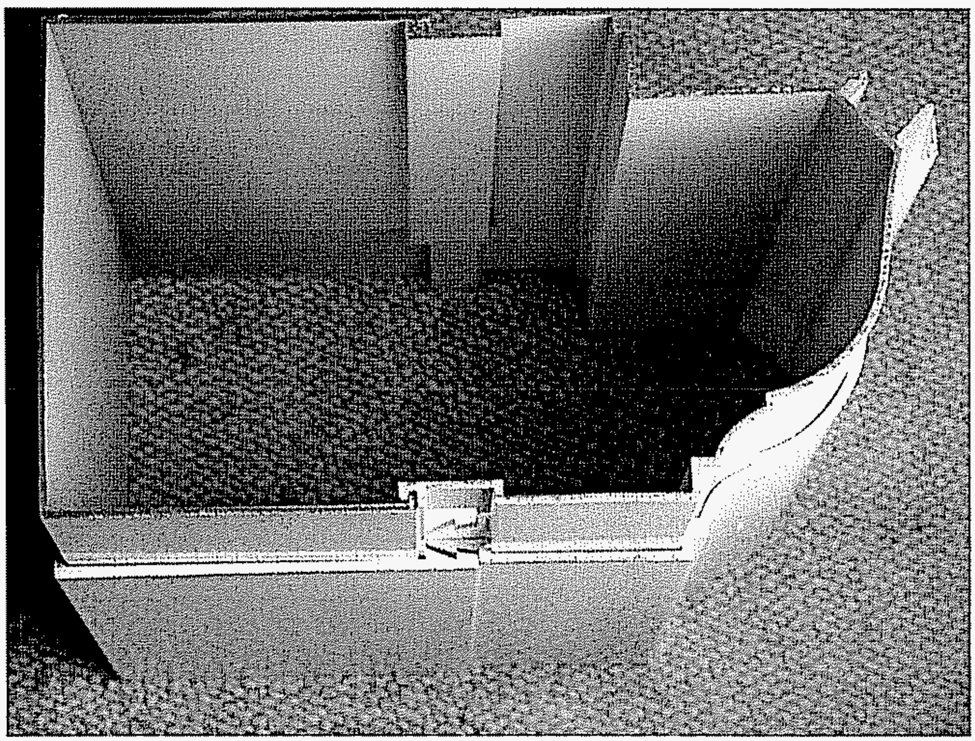
The next image is the sequence of all extrusions generated as part of the second extrusion set:



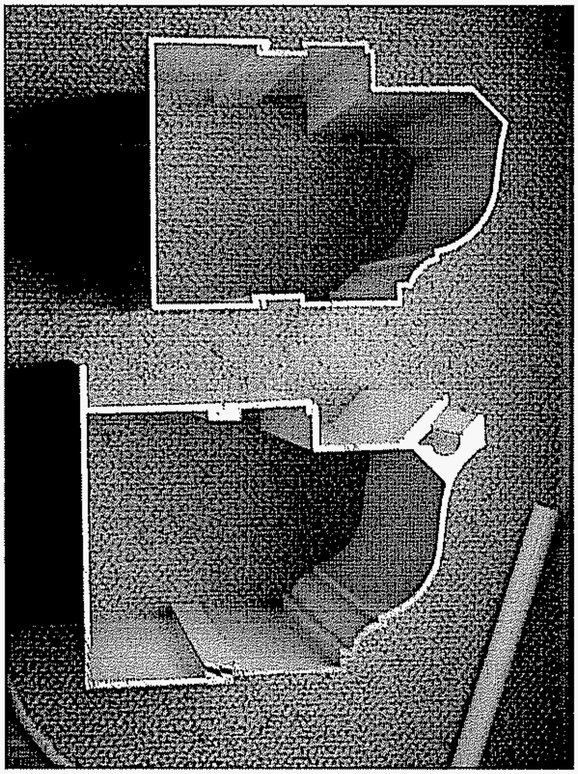
The following photograph shows the deep version of the second set of aluminum extrusions. The set of extrusions at lower left is the deep back piece and the front piece snapped together to form the duct. The two extrusions snapped together at the upper right of the photo represent the connection piece for splicing together sections of duct.



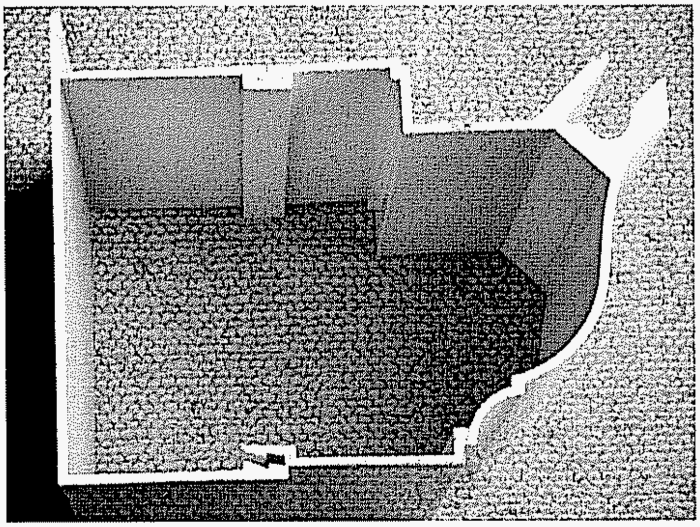
The next photo shows the connection piece inserted in the duct:



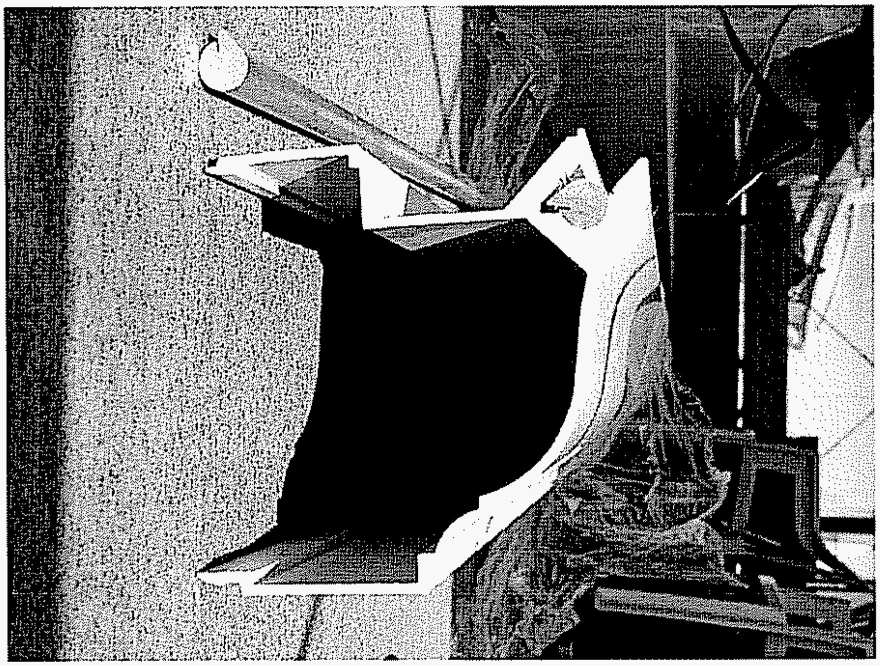
Note that the snap mechanism did not function properly on this particular set of extrusions. The engineers at the aluminum extrusion mill re-extruded the shapes, making some adjustments in the system used to cool the extrusion and adding constraining elements to help control the shape immediately after emerging from the dies. These methods did not succeed in adequately controlling the shape of the extrusion. It was also perceived that these methods were cumbersome and were substantially increasing production costs. The failure of these methods made it necessary to redesign the dies. The extrusion engineers raised concerns that even redesigning and remaking the dies might not achieve the desired tolerances. After great deliberation, it was decided to generate an alternate design (Extrusion Set 3). The next photograph shows the shallow version of the duct and the shallow connector piece from extrusion set two.



In the following close-up, it is apparent that the snap mechanism is even more out of alignment on this extrusion than on the previous one:

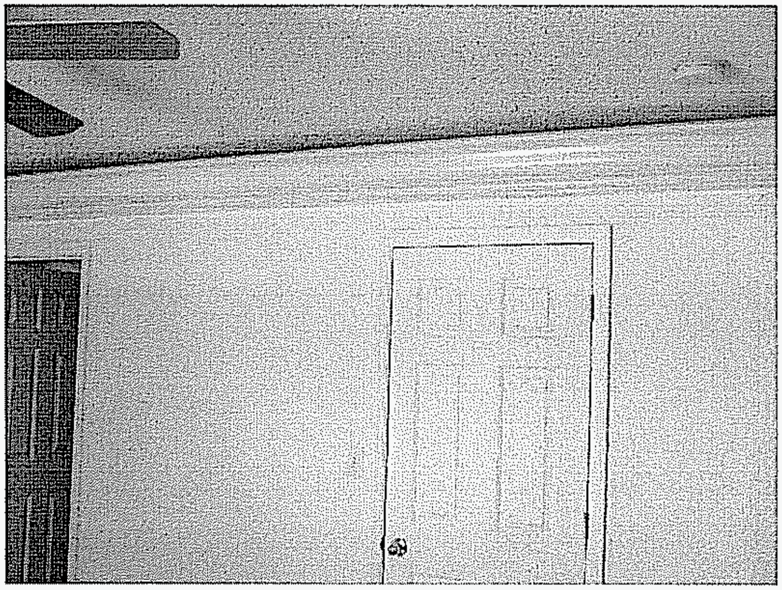


The next photograph shows a close-up of the air controller mounted in the slot in the front extrusion. Rotating the air controller regulates the air flow. Not visible in this photo are slots cut in the duct extrusion to allow air flow to occur through the duct wall right behind the air controller. Visible in the air controller is a slot to accommodate a flexible neoprene seal. It was ascertained that this seal was not required to get a close fit to seal off the air. This represents a significant simplification to the assembly of the system.

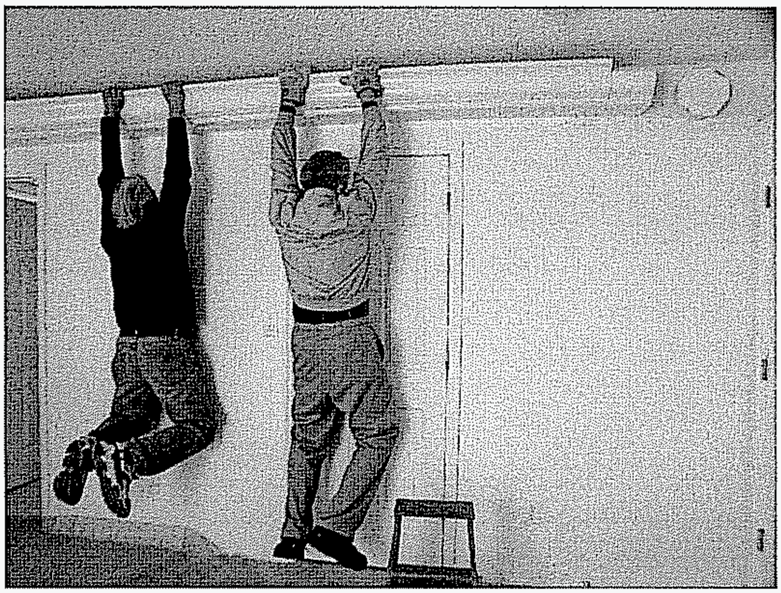


For the purposes of thermal testing, the lack of snap was overcome by screwing the extrusions together. (This mechanical fastening procedure was not terribly time consuming for the purposes of one-off testing, but it was deemed undesirable for standard field installations.) The thermal testing was useful for testing the air-flow pattern and air-flow control.

The following photo shows a run of extrusion set 2 installed in the laboratory house:

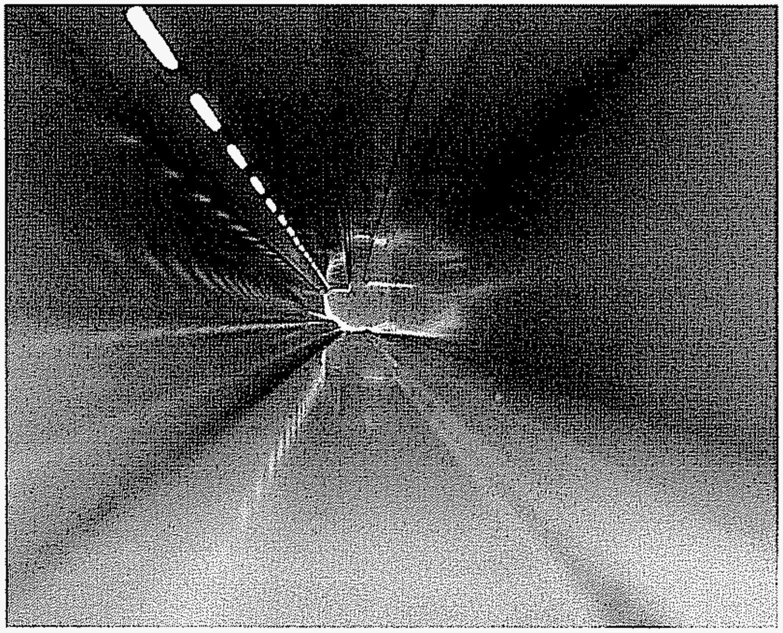


The next photo shows the structural testing procedure:

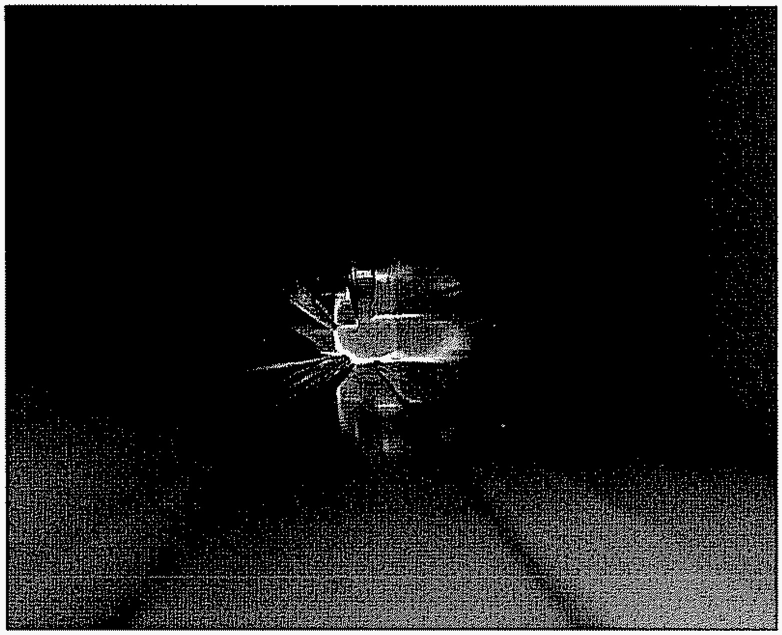


Under this 400# load, the observed deflection was consistent with the predictions of the structural simulations performed during the design phase of the duct.

The following is an interior view of the duct with the orifices open:



The following is an interior view of the duct with the orifices covered with the air controller:



Notice how little light is coming in through the orifices, even though the unit was installed with only the naked aluminum controller with no neoprene seal. The overwhelming amount of light entering the duct is coming from the tiny gap where the duct meets the wall.

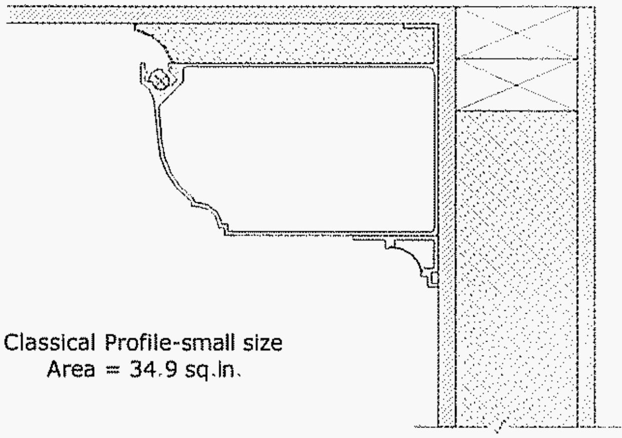
The orifices in extrusion set 2 were slots approximately 1/8”-wide by 4”-long set at 6” O.C. The slots were cut using a circular saw mounted on a milling machine. The plunge mechanism on the milling machine allowed the cutting of discrete slots by plunging the saw into the wall of the duct.

Flow testing on Extrusion Set 2:

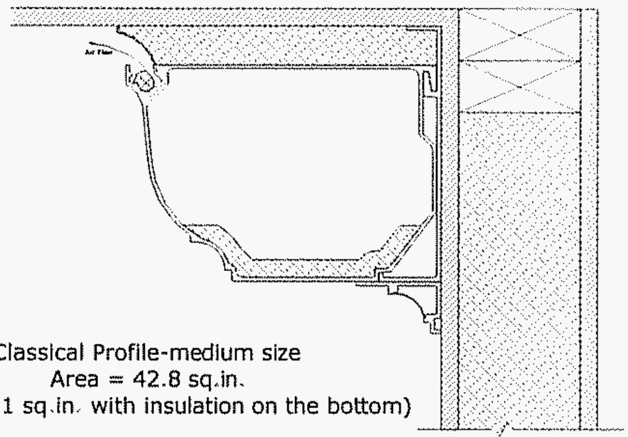
Flow testing on extrusion set 2 was qualitative. It indicated that the flow rate was lower than desired and that the pressure drop at the fan was greater than desired. For this test the Alnor anemometer was used to measure the velocities of the air exiting the CorniceAire System duct. It was noted that flow from the duct was approximately equal to that of the original prototype provided that the air controller was completely removed from the duct. This is not a desired design configuration. This was a significant additional motive to redesign both the extrusion and the method of slotting the orifices. Also of major concern was a tendency for the system to whistle when the air controller was used to throttle back the flow rate. It was decided that the whistle problem would best be addressed by changing both the size of the orifices and the shape of the air controller.

Extrusion Set Three

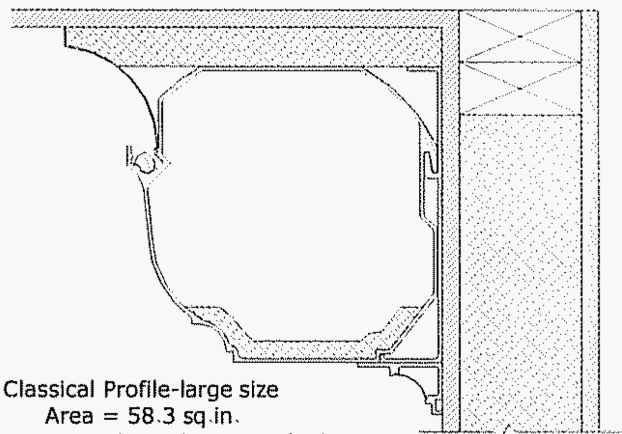
For extrusion set three, it was decided to extrude a hollow duct that was a monolithic tube. The practical limit for extrusion presses was 12". To get good flow of the material, make sure the material rejoined on itself thoroughly, and avoid contamination from surface oxide on the billet, it was decided to keep all extrudes shapes within a 10" circle. This presented a serious challenge in terms of getting an aesthetic form and, at the same time, getting a large enough cross-sectional areas for conducting ample quantities of air. The following represents a sequence of sizes of duct that came out of this design exploration:



Classical Profile-small size
Area = 34.9 sq.in.



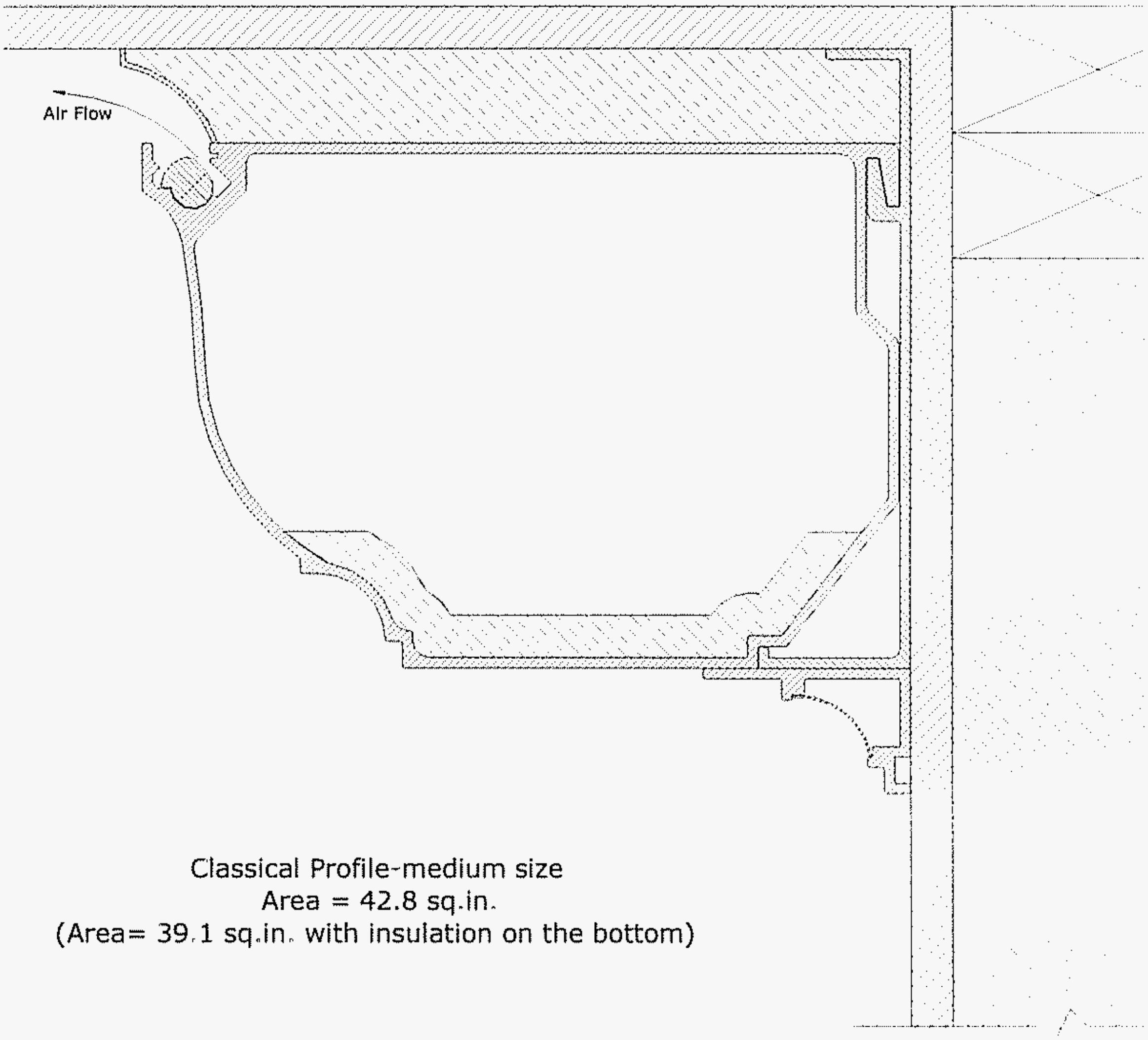
Classical Profile-medium size
Area = 42.8 sq.in.
(Area= 39.1 sq.in. with insulation on the bottom)



Classical Profile-large size
Area = 58.3 sq.in.
(Area= 54.6 sq.in. with insulation on the bottom)

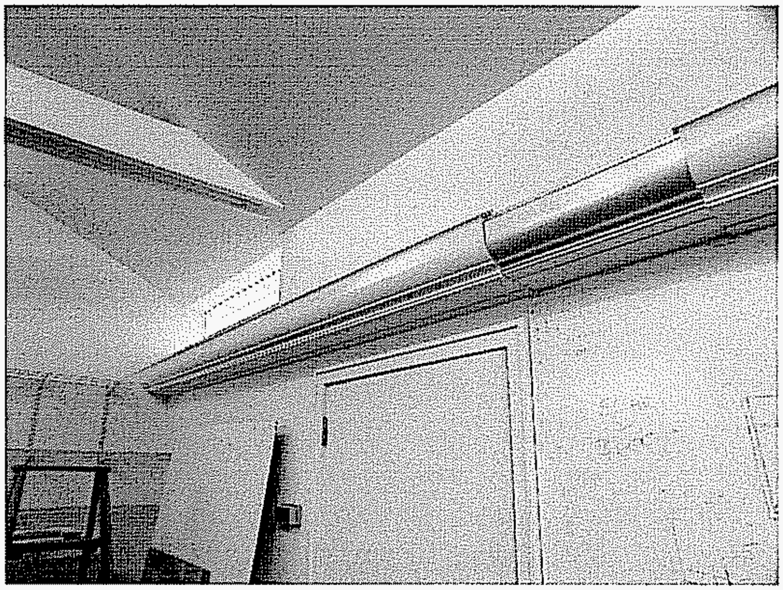
The for the medium and large sizes, the odd "rounding" of the back side of the duct is a result of the limitation that the duct cross section had to fit within a 10" circle.

The decision was made to extrude the medium-sized duct, which is shown closer up in the following image:



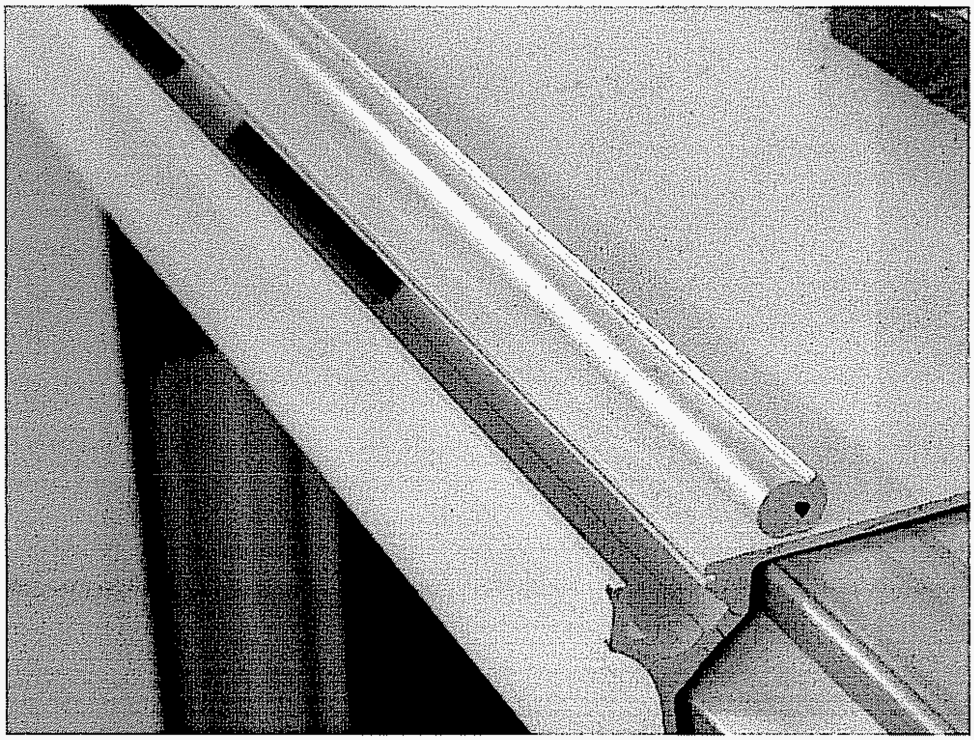
Classical Profile-medium size
Area = 42.8 sq.in.
(Area= 39.1 sq.in. with insulation on the bottom)

The following photograph shows a run of extrusion set 3 installed a the Daylighting Research Facility at North Carolina State University:



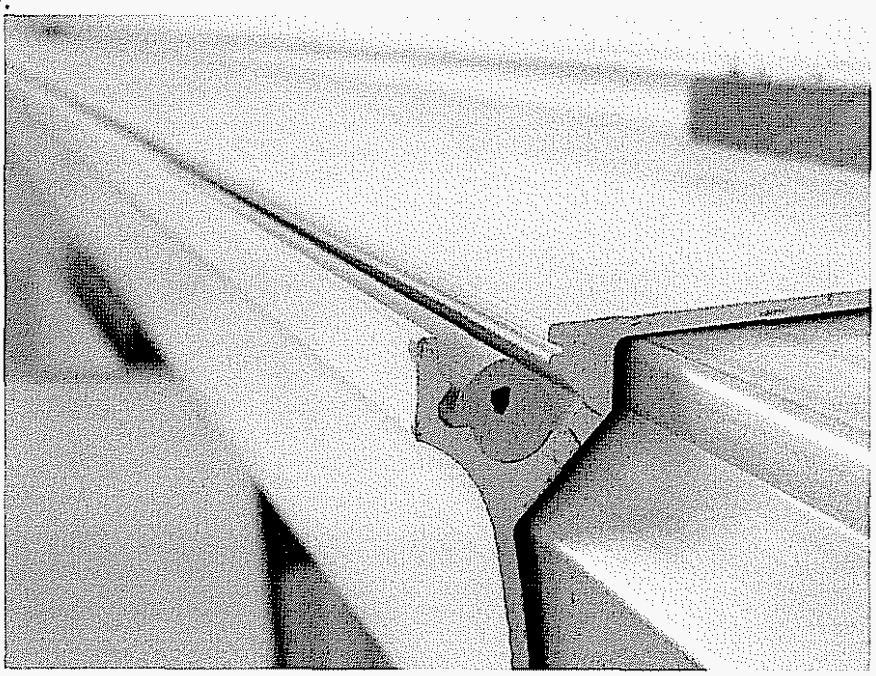
The shiny metallic part is the connector, which in this case has a large rectangular hole cut in the back of it to admit air from the air-handling unit.

The next photograph shows a close up of the duct, showing the slots and the air controller resting on top of the duct:



The following image shows the controller seated in the duct cavity in the closed position:

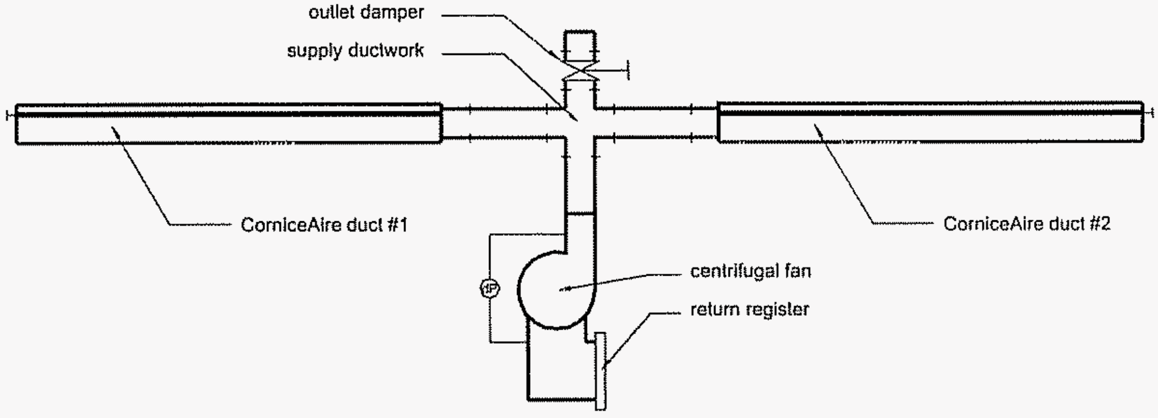
The following image shows the controller seated in the duct cavity in the open *position:*



Notice how the air controller is rounder than the one used in extrusion set 2. The revised shape solved the whistling problem that was noted in the testing of extrusion set 2. Another very satisfying result of the experiment was the following: stable continuous control of the air was achieved without springs to hold the air controller in place. Therefore, the air controller can be fabricated as a single extrusion, without any neoprene of soft sealant, and can be installed by simply dropping it into the depression provided for it!

Flow testing of Extrusion Set 3:

Test instrumentation was used to measure the pressure rise through the supply fan. It was installed as shown in the following figure:

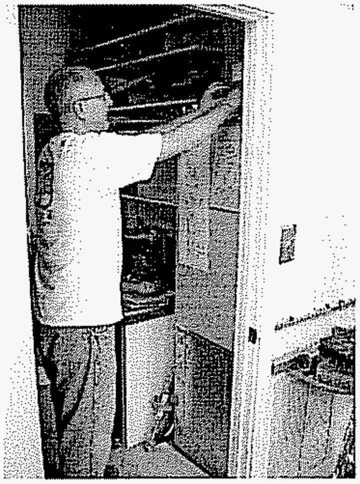


flow
testing system

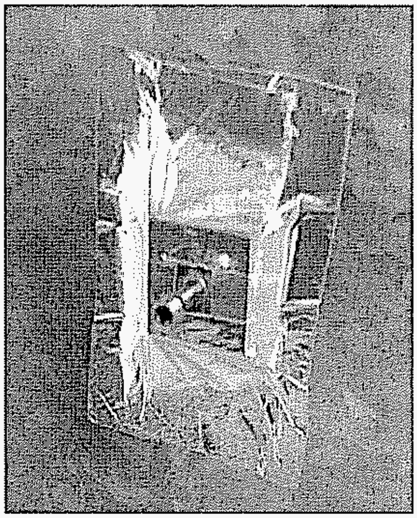
dP = delta pressure

The system was aligned with the bypass and both CorniceAire System ducts open. Pressure rise (dP) through the fan was measured in inches of water using the Dwyer Series 475 Mark III digital manometer. The flow through the outlet damper was adjusted so that the fan was performing in the normal dP range for this fan as specified by the manufacturer. The dP was measured again with one CorniceAire System duct closed. Then the dP was measured with the other duct closed. Finally the measurement was taken with both ducts closed. In each case the recorded dP was compared to the manufacturer's fan curve to estimate the flow through the fan. The results of this test showed that the ducts would produce about 40 cubic feet per minute (cfm) for each duct. Each of the ducts was 10 feet long and had a 3/16" wide by 4" long slot every 6 inches. There were a total of 19 slots in each duct for a total area of 14.25 square inches of opening in each duct. This shows that the ducts as constructed in extrusion set 3 would produce about 4 cfm per foot of duct.

The following image shows the air-handling unit at the Daylighting Research Facility:

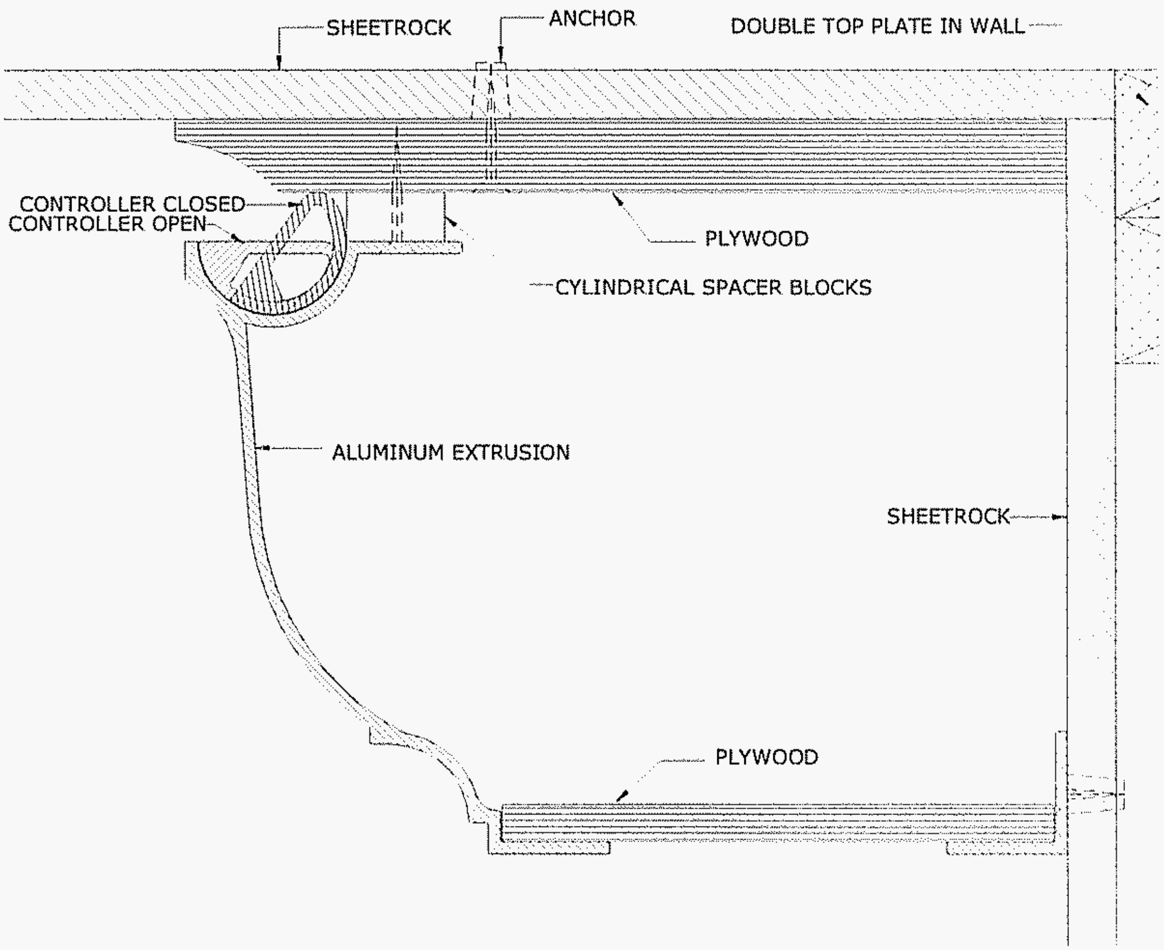


Pitot meters were installed in the return plenum (at the bottom) and at the outgoing plenum (at the top), as shown in the following photos:



The slots for the orifices were cut using a hydro-cutter and were made about 3/16"-wide x 4"-long. They were intended to be 1/4"-wide, but the hydro-cutter had trouble getting the cutting tool in close enough to the work. Increasing the width of the slot to 3/16"-wide did not completely solve the problem of low flow rate and excessive pressure drop at the fan.

This problem should be addressed in the final Cornice Duct design shown in the next image:



In the scheme above:

- The slot width is 1/2", allowing for a far wider range of flow rates than in previous models.
- The slot width is set by using cylindrical spacer blocks with screw holes through the middle, rather than by slotting the extrusion. These cylindrical spacer blocks would probably be made out of aluminum or plastic in the final version, but for testing purposes, they could be made out of wood dowels cut to length. They could also be made out of stacks of washers, if the washers could be found with a consistent thickness.
- Plywood has been used on top to provide both structure and enough insulation to help get conditioned air all the way to the end of the run.
- Plywood has been used on bottom to provide enough insulation to help get conditioned air all the way to the end of the run. These materials would be lined with aluminum foil to add to the thermal barrier and also to keep the wood from drying out too much from exposure to hot, dry air.
- The air controller would probably be aluminum in the final version, but it could be made out of wood or plastic for testing purposes.

Electric lighting for the Cornice Duct:

We have been working with Marcus Early Lighting and are having conversations with the Research Division of Peerless Lighting regarding various lighting options.

From the beginning of this project, we have held the desire to produce a lighting system where the lamps would be a truly integral part of the Cornice Duct. Achieving this goal has always faced a number of obstacles:

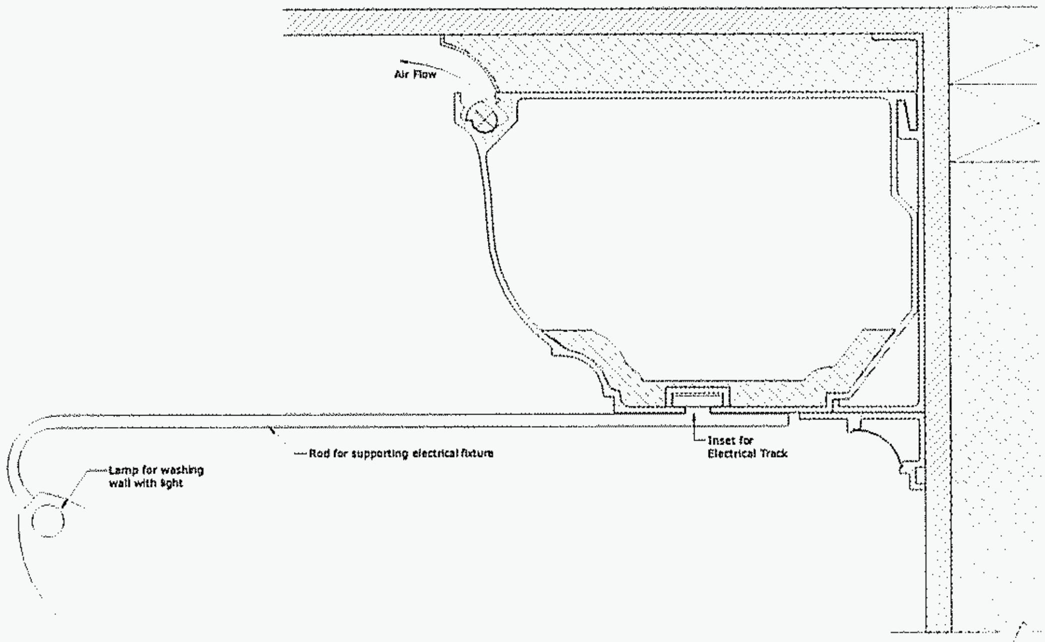
1. We have always suspected that light from lamps mounted close to the ceiling would cause aesthetic problems in that the light grazing the ceiling surface would visually amplify any irregularities in the ceiling. In the original mockup of this device, we incorporated lamps very close to the surface that was used to simulate the ceiling above the device. That surface was fabricated to be extremely accurate and the response of people involved in assessing the product was very favorable, since even the shallow grazing angle revealed no significant visual defects in the surface. However, after experimenting with lamps close to the ceilings of several houses more representative of typical construction, we have concluded that the aesthetic problems are serious and there is no practical value in pursuing versions of the device with lamps mounted really close to the ceiling. Therefore, upwardly directed lights that are integrated in the duct will only make sense when the duct is mounted well below the ceiling, such as in a shelf configuration.

2. In a similar vein, we have concluded that wall-washing lights will not give satisfactory illumination unless they are removed from the wall surface by a dimension substantially larger than the horizontal dimension of the duct. Therefore, there is no merit in the idea of using lamps integrated into the duct to illuminate walls.

3. There are concerns regarding how stable and efficient fluorescent lamps will be when subjected to the combination of their own heat and the heat from the duct. Long-term testing would have to be done for any truly integrated system. This may be a mute point in the end, since the only practical lighting version with the fixture situated close to the duct seems to be to mount the duct low on the wall and since ducts mounted low on the wall will be able to accommodate a thermally insulating barrier on the top which would help shield the fluorescent fixture from some of the negative thermal consequences of the duct. In this case, however, there will be no true integration of the duct and the lighting and it may make more sense to simply find independently produced lighting fixtures that can be mounted on top of the duct.

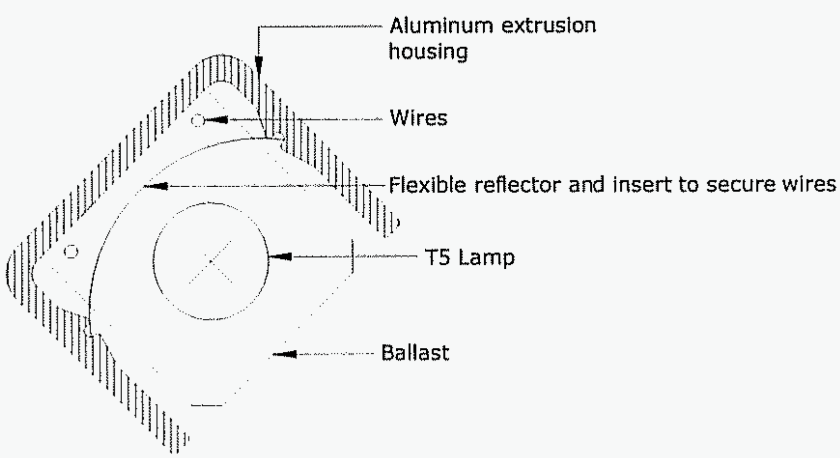
There are two integrated concepts that are still under serious consideration:

1. A track-lighting power strip embedded in the duct housing that would allow lighting fixtures to be mounted for either ceiling or wall washing, with the fixtures much further from the wall or ceiling than would be allowed if the fixtures were truly integrated into the Cornice Duct housing.

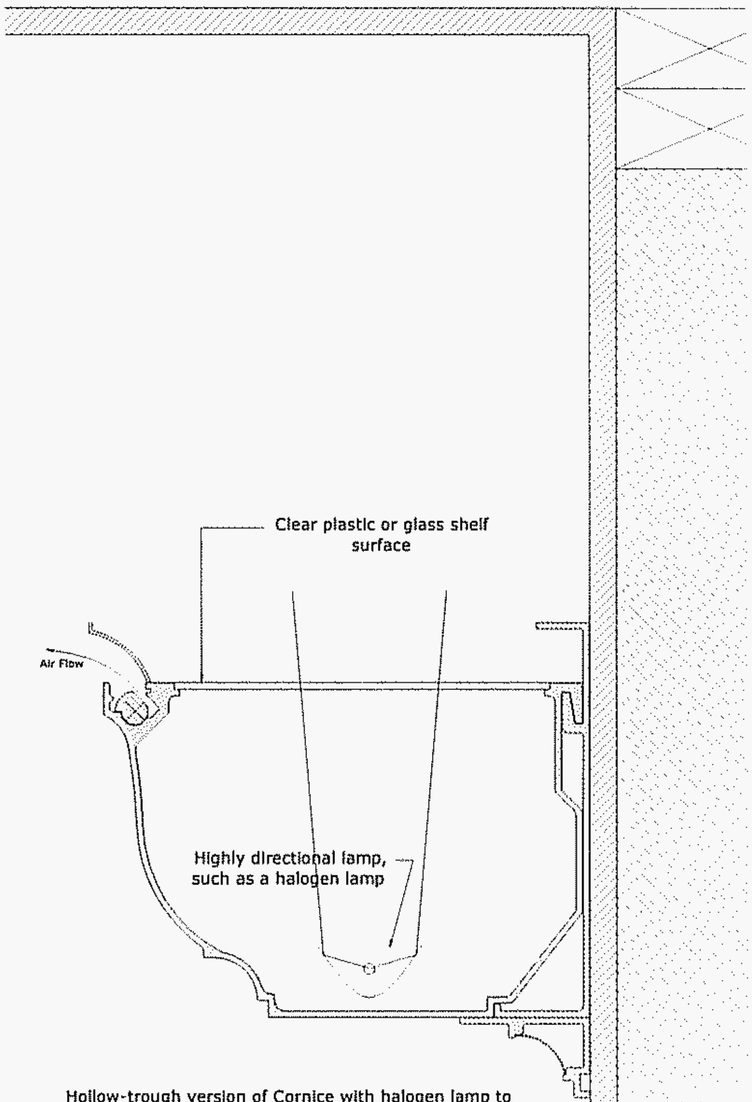


Track-light fixture options:

- Near term: use Micro-Strip T5 from Legion Lighting Co., Inc. in Brooklyn, NY.
- Longer term: adapt T5 Lamp and a compact ballast similar to the one in the Micro-Strip T5 in an in-line configuration that produces a more compact overall fixture. Focus on shape and aesthetics, since it is really going to be visually prominent. As an example:



2. A hollow trough that would be part of a shelf system surrounding a room, wherein the trough would not actually be a duct to conduct air, but would be the same in its visual appearance as a duct, thereby creating the illusion of a complete decorative element, or shelf, ringing the room. In this case, the shelf would have a clear glass or plastic surface on which objects could rest, with the lamps mounted under the protective glass or plastic material. This option would be deep enough to accommodate intense, highly focused light, such as halogen lamps, which would be particularly attractive for the display of elements such as cut glass, which will not sparkle under diffuse light from fluorescent lamps.



Hollow-trough version of Cornice with halogen lamp to illuminate crystal on the shelf

For the purposes of this project, there was not enough money to complete the fabrication and testing of the last two options. However, with sufficient testing, they may prove viable at some time in the future.

For the purposes of this contract, we are incorporating electric lighting as an add-on feature, to simulate the overall look and performance, without full integration. The only electric lighting installation currently planned will be in the new building to be constructed at the North Carolina State University Daylighting Facility.

Task 2.5 – Product Evaluation

The recipient shall evaluate all data acquired in Task 2.3 with regards to performance and cost of the Cornice Duct System and with regards to any design or manufacturing refinements necessary to improve the system and make it commercially available.

The Recipient shall develop design guidelines, specifications, and cost projections for the Cornice Duct System derived from the work set forth in this proposal.

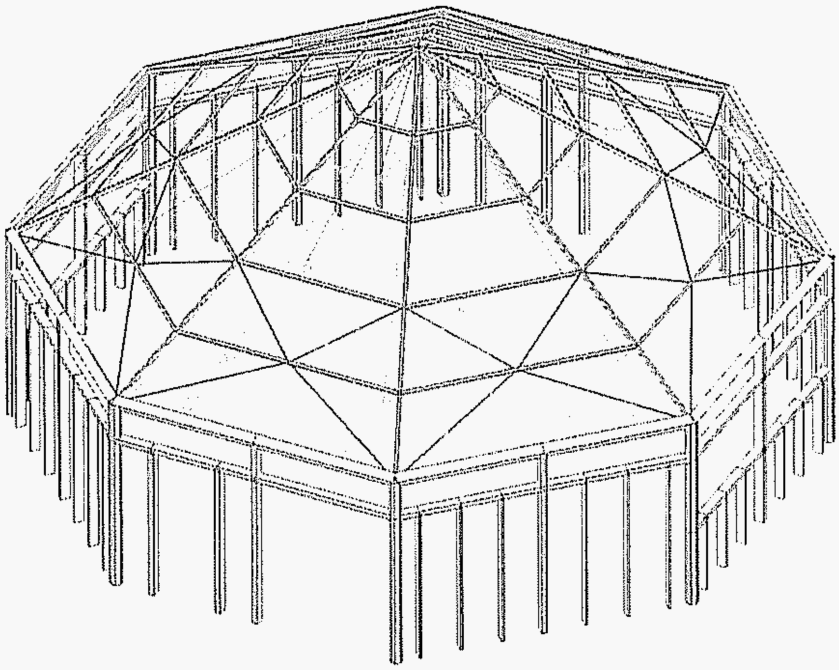
The Recipient shall develop detailed architectural information on an assortment of Cornice Duct System profiles and details for a variety of residential applications. The residential applications shall include application of the Cornice Duct System to ranch, raised ranch, split level, and multistory house styles. Connection of the air handling unit(s) shall be considered and described.

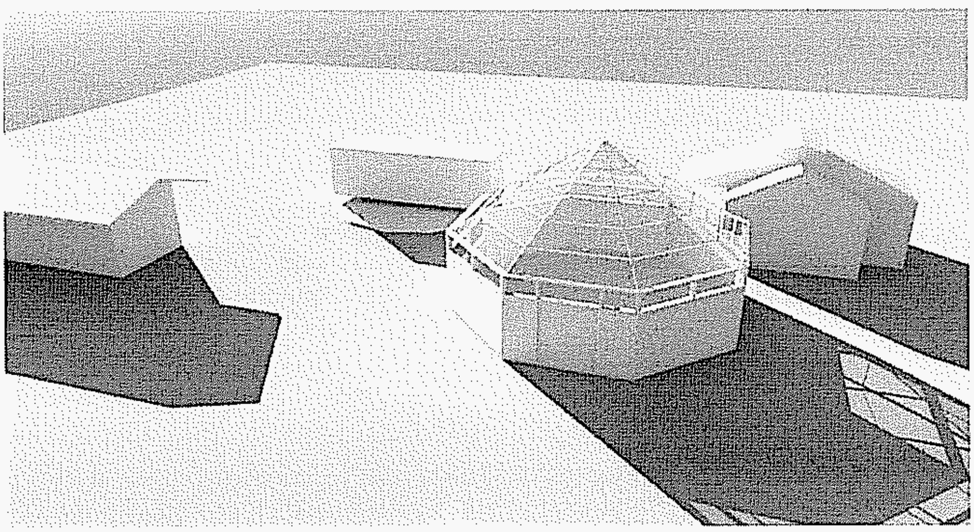
The Recipient shall compile the design guidelines, cost projections, specifications, architectural information, and experimental results, in formats that can be used to present the Cornice Duct System to potential installers and manufacturers and at industry conferences.

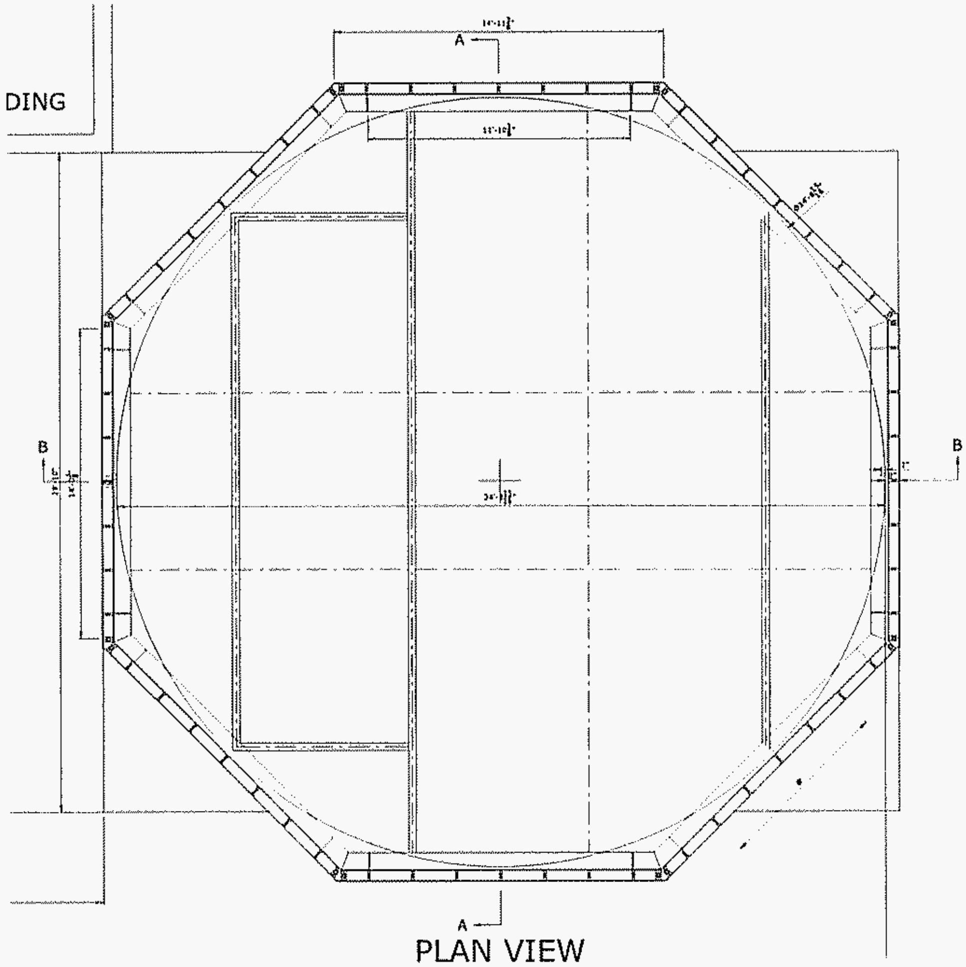
> This work is complete.
> See attached Document titled:
> Design Guidelines for CorniceAire Internal Air Distribution System

Planned future activities to be carried out as follow-on to the DOE contract:

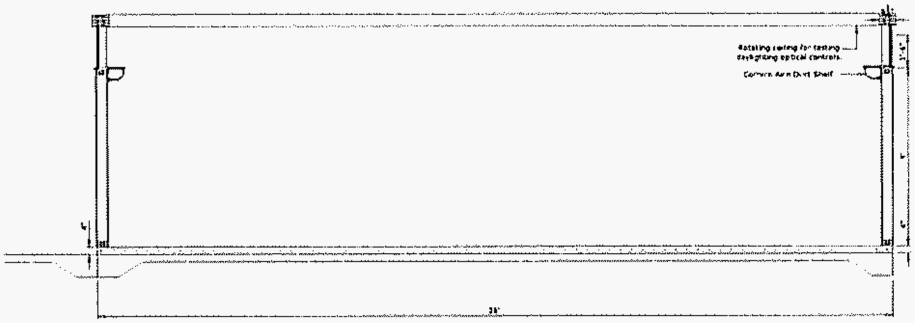
We plan to install the Cornice Duct in a Demonstration Building on the North Carolina State University campus. The required extrusions for this installation have already been stockpiled and they await the construction the building. The primary function of the building is for testing optical controls for roof-based daylighting systems. To facilitate this testing, the roof will be an extremely transparent glazed roof, with an insulated, rotating ceiling of modular construction that will allow various optical elements to be inserted. Below the ceiling will be clearstory glazing and below the clearstory will be the cornice duct. The following images are of the planned new building.



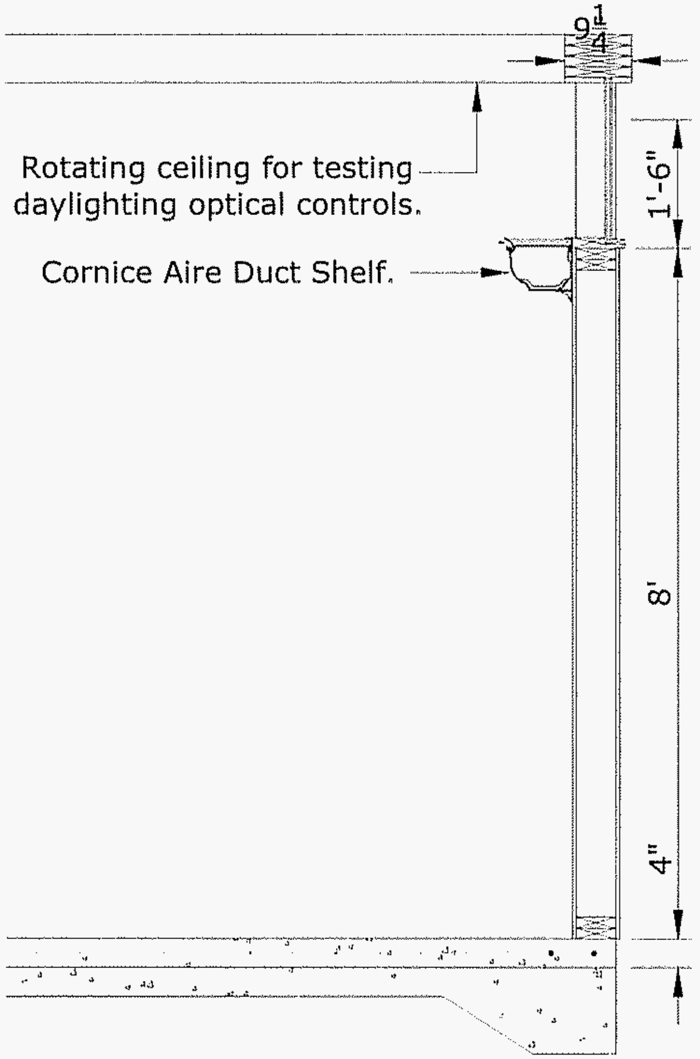




PLAN VIEW



SECTION B-B



We had hoped to install the Cornice Duct in a townhouse for visual presentation purposes. This would have been done if the aluminum mill had agreed to re-extrude the extrusion set 3 to higher dimensional tolerances. They did agree to re-extrude, but the standard that they were willing to set was still regarded as too low for the visual application in the townhouse. However, the tolerances of extrusion set 3 are high enough to put into the demonstration building being constructed at the university. The difference in the two situations is that the volume and ceiling height of the demonstration building will allow the use of trim pieces to disguise tolerance errors in the extrusions. Using similar trim pieces in the Townhouse would have created an installation that was out of scale with the size of the rooms.

We have been working with Marcus Early Lighting and are having conversations with the Research Division of Peerless Lighting regarding various lighting options.

We have been in touch with Phil Spartz of the California Energy Commission, who is interested in using the Cornice Duct in some of their demonstration houses. This seems like a good opportunity to accelerate the process of adoption.

We have had discussions with a group in Atlanta, GA, regarding possible commercialization of the product.

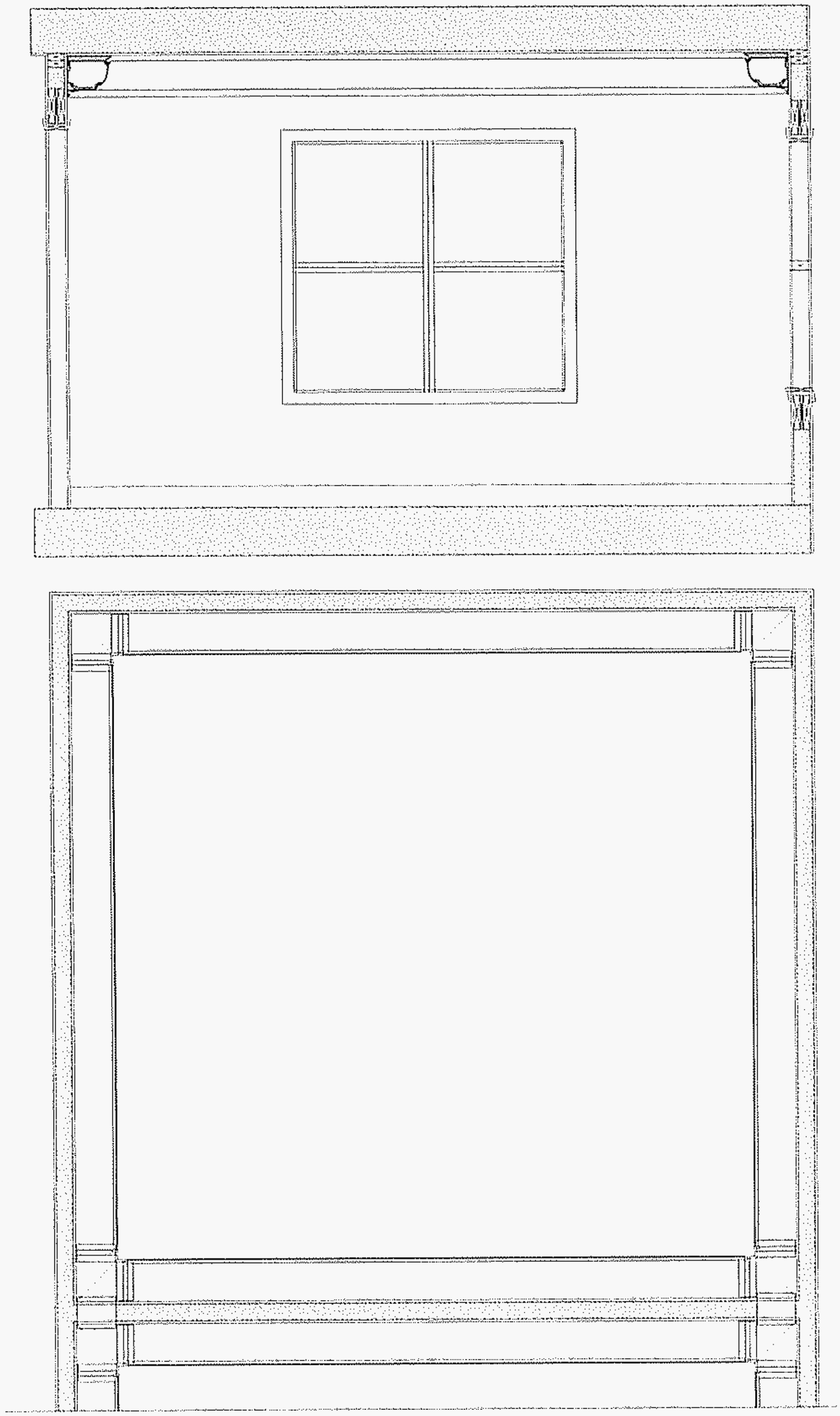
We will be having conversations with Arun Vohra about doing an article and presentation for the next ASHRAE conference.

Design Guidelines for

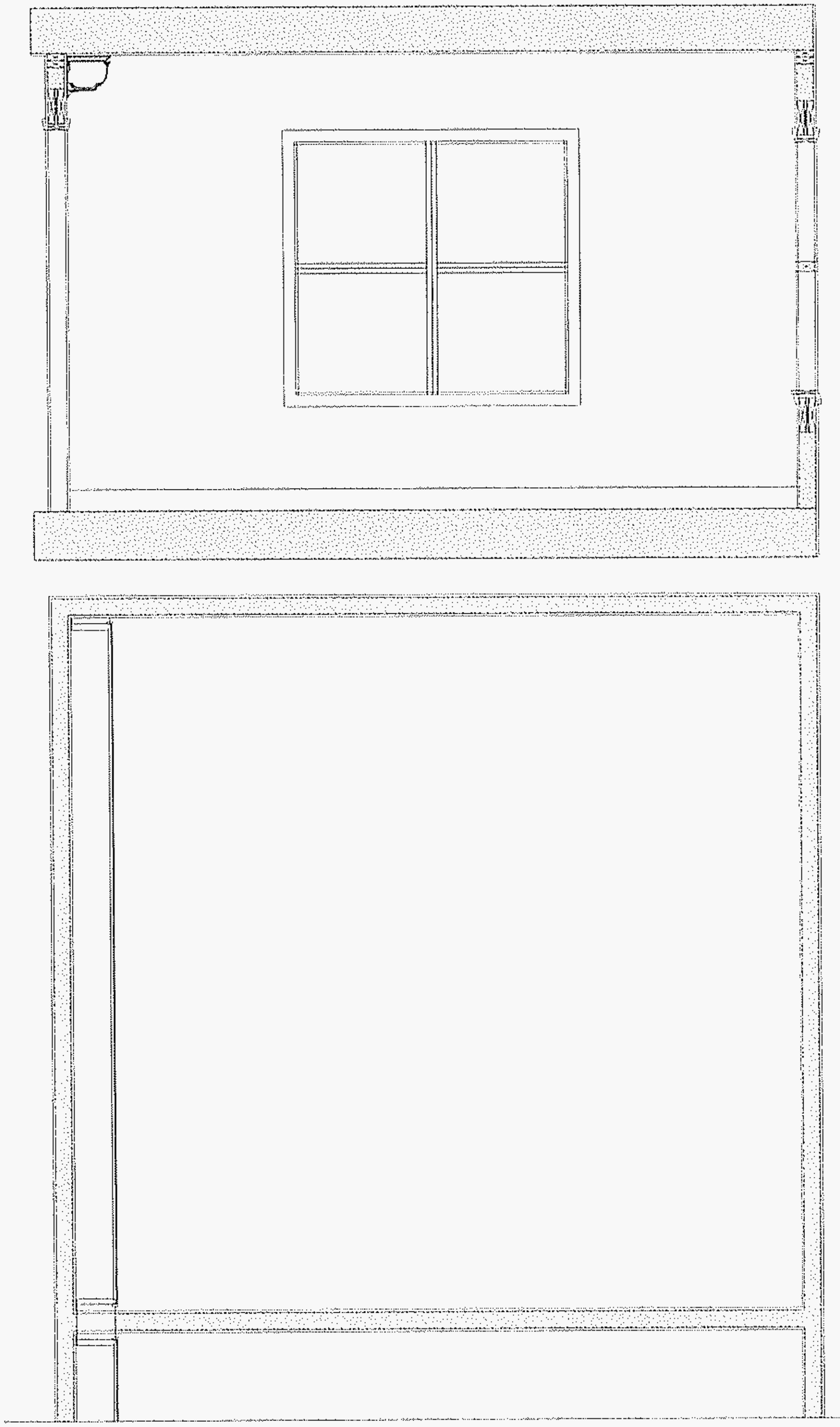
CorniceAire Internal Air Distribution System

The CorniceAire system is designed to gently deliver conditioned air throughout the interior spaces of a residence using ducts that are contained entirely within the thermal envelope of the house. This is in contrast to the more conventional method of transporting conditioned air through ducts that are located in attics and crawl spaces. Duct leakage and conductive losses in such thermally uncontrolled spaces can result in 30% energy losses in attics and 15% energy losses in crawl spaces. In the case of the CorniceAire system, the minor air leakage and conductive heat transfer through the duct walls do not constitute an energy loss, since they deliver the heating or cooling to spaces that require that thermal conditioning anyway.

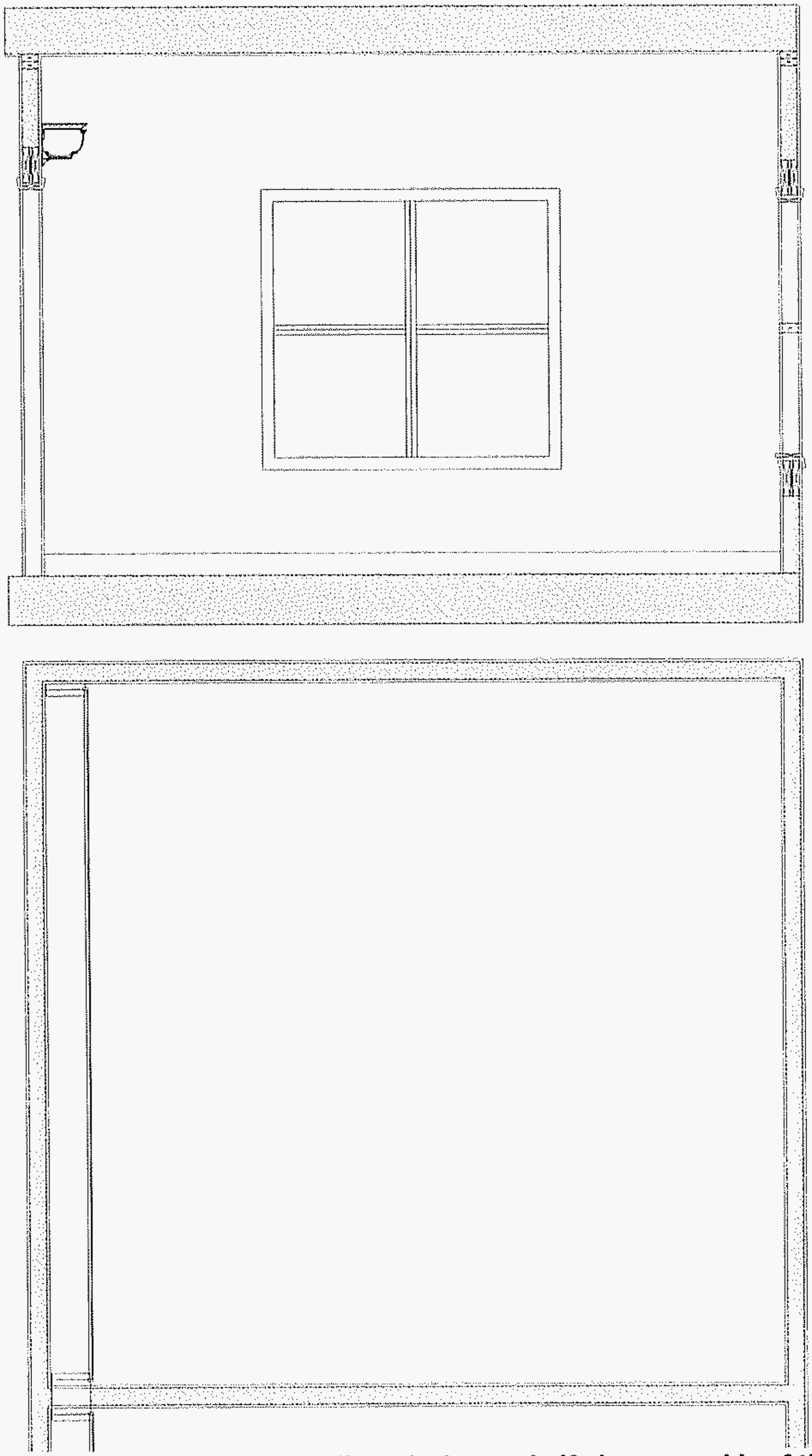
The greater energy efficiency of the CorniceAire system allows for lower flow rates, resulting in less noise, gentler air movement, lower fan power, and improved energy efficiency of the condenser and fan-coil units in the thermal plant.



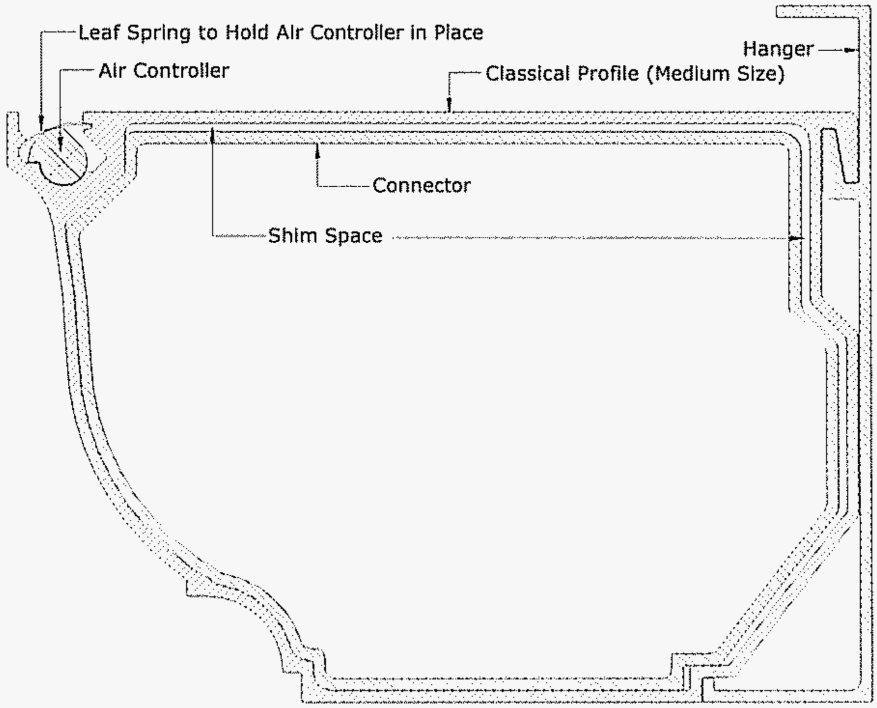
Classical Profile of CorniceAire (medium size) going all around the ceiling



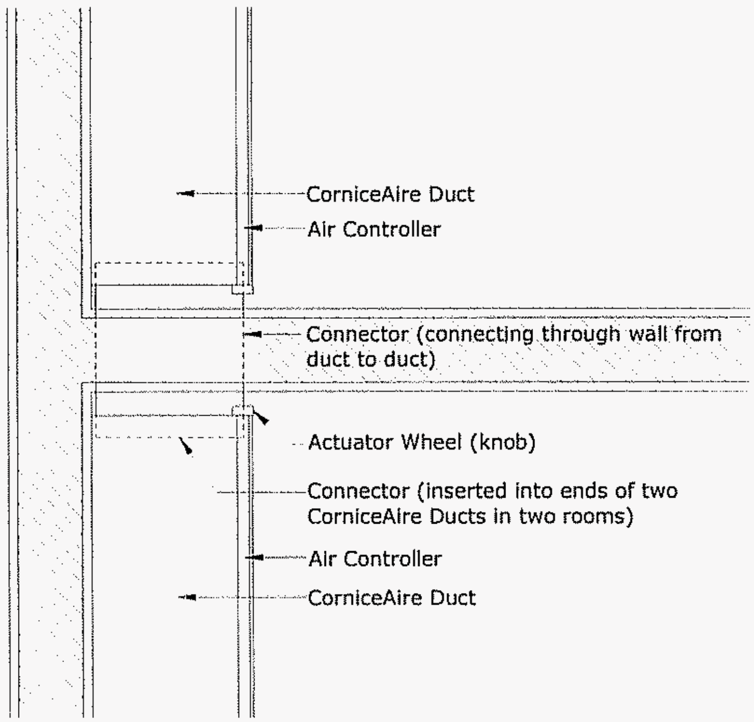
Classical Profile of CorniceAire (medium size) along one side of the ceiling



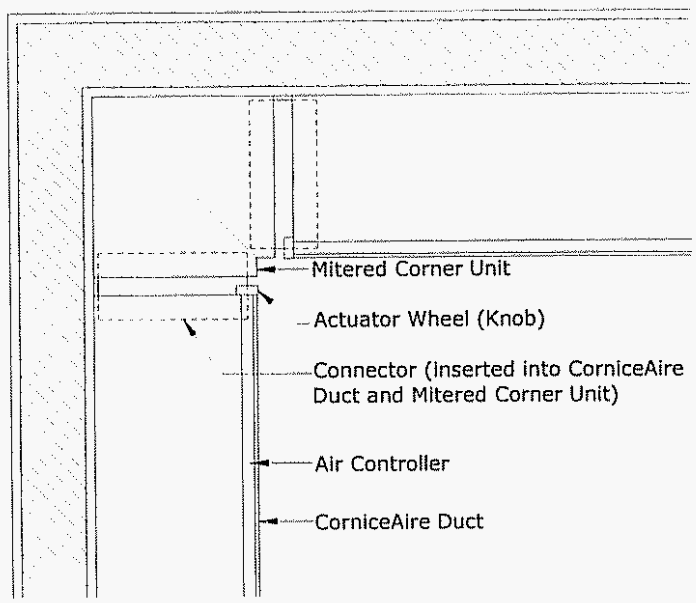
Classical Profile of CorniceAire (medium size) as a shelf along one side of the room



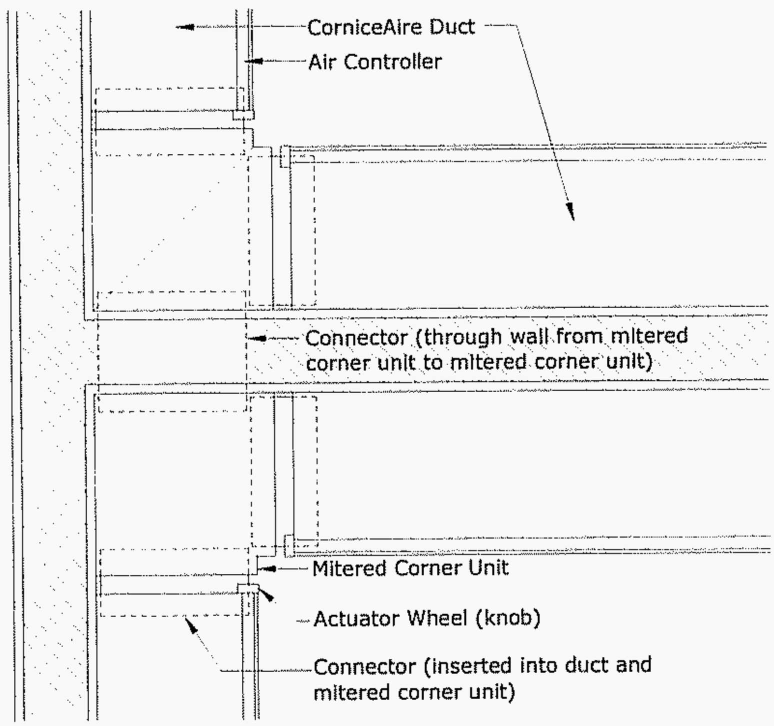
**Classical Profile of CorniceAire:
Sectional view showing Connector**



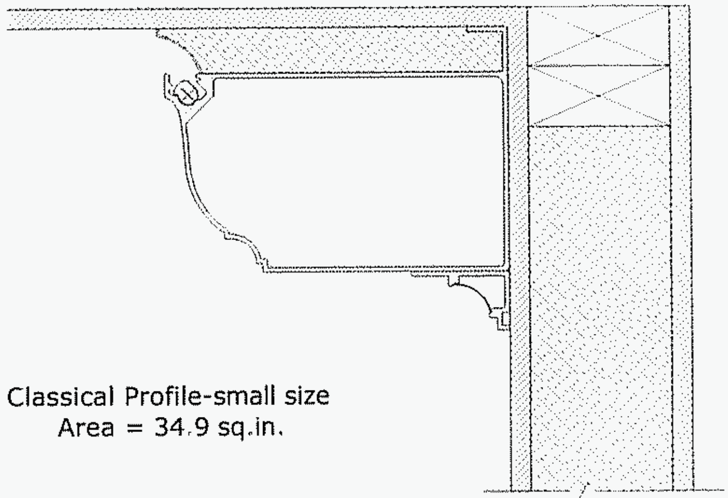
**Connection of CorniceAire Duct sections through the wall:
Plan view showing Connector joining two sections of CorniceAire Duct on opposite sides of the wall**



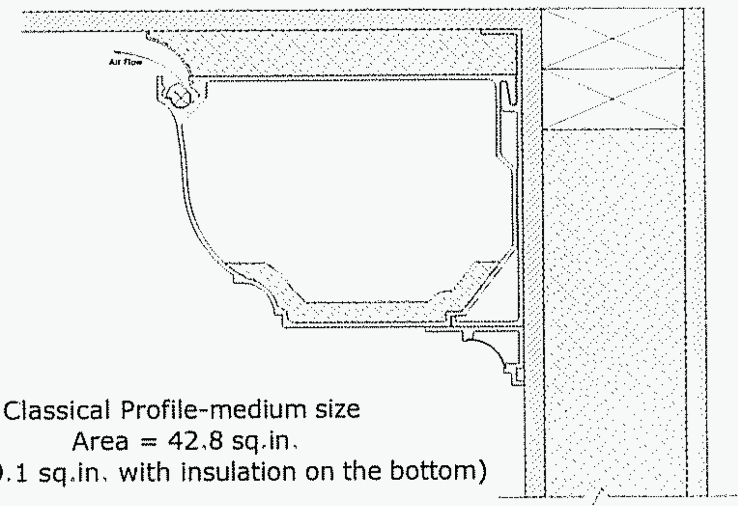
Connection of CorniceAire Duct to a Mitered Corner Unit:
Plan View showing Connector between CorniceAire Duct and Mitered Corner Unit



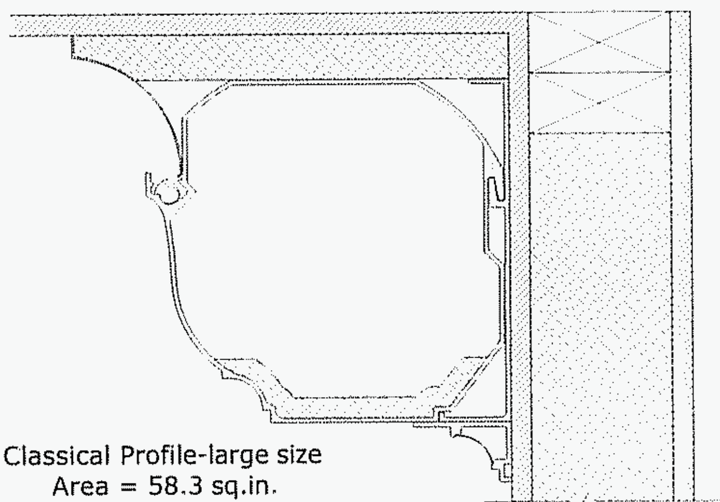
Connection of Mitered Corner Units through the wall:
Plan View showing Connector between Mitered Corner Units on opposite sides of the wall



Classical Profile-small size
Area = 34.9 sq.in.

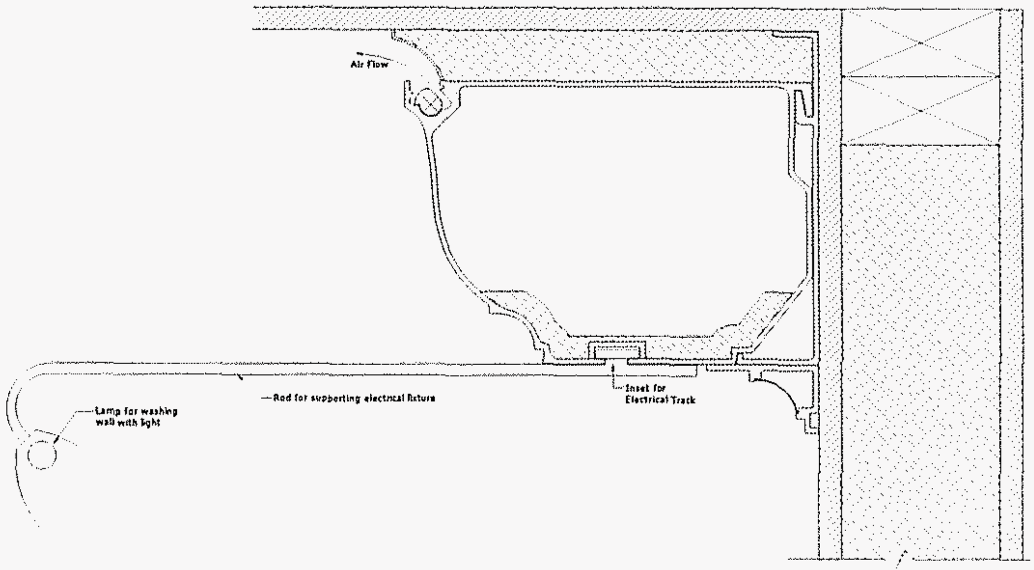


Classical Profile-medium size
Area = 42.8 sq.in.
(Area= 39.1 sq.in. with insulation on the bottom)



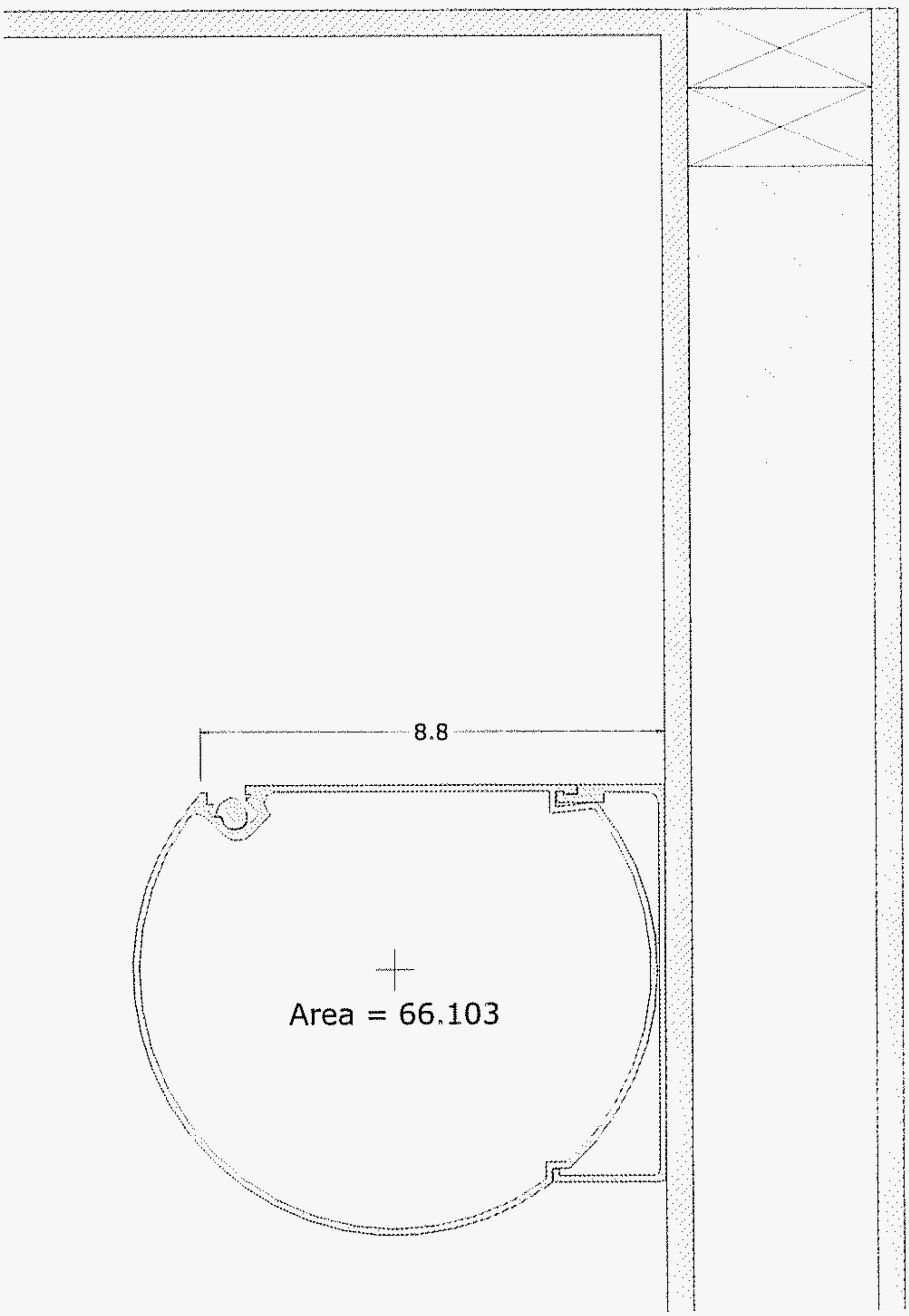
Classical Profile-large size
Area = 58.3 sq.in.
(Area= 54.6 sq.in. with insulation on the bottom)

Classical Profiles of the CorniceAire for mounting as a cornice near the ceiling, but also suitable for mounting lower on the wall to use as a shelf

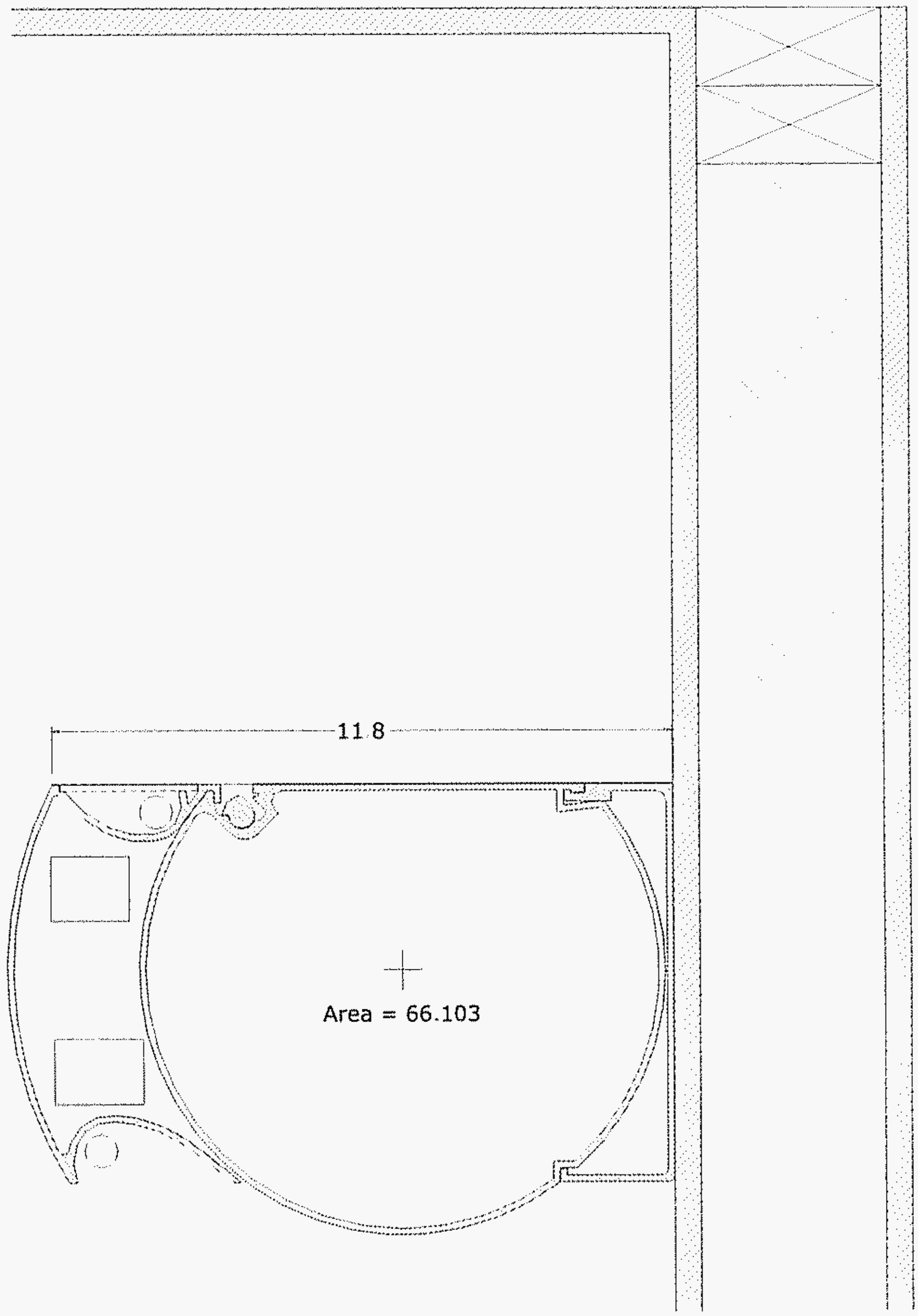


Track lighting option for the Classical Profiles

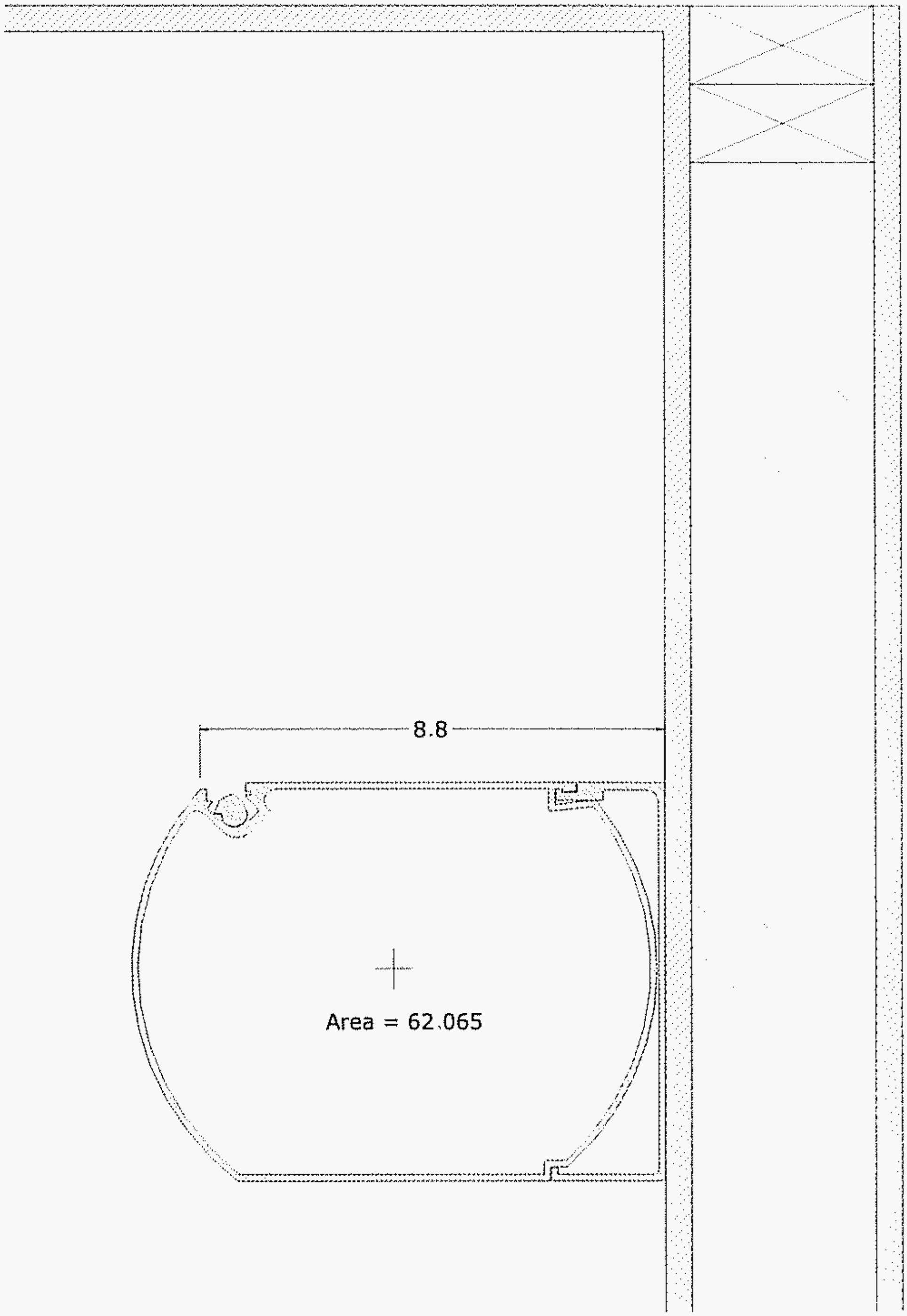
The following pages contain CorniceAire Profiles that were designed predominantly for use as a shelf mounted on the wall well below the ceiling. All of these profiles are shown without insulation on the top of the duct. However, there will be situations where that insulation will be crucial and it is always an option to allow conditioned air to penetrate further into the network with reduced thermal losses to intervening spaces.



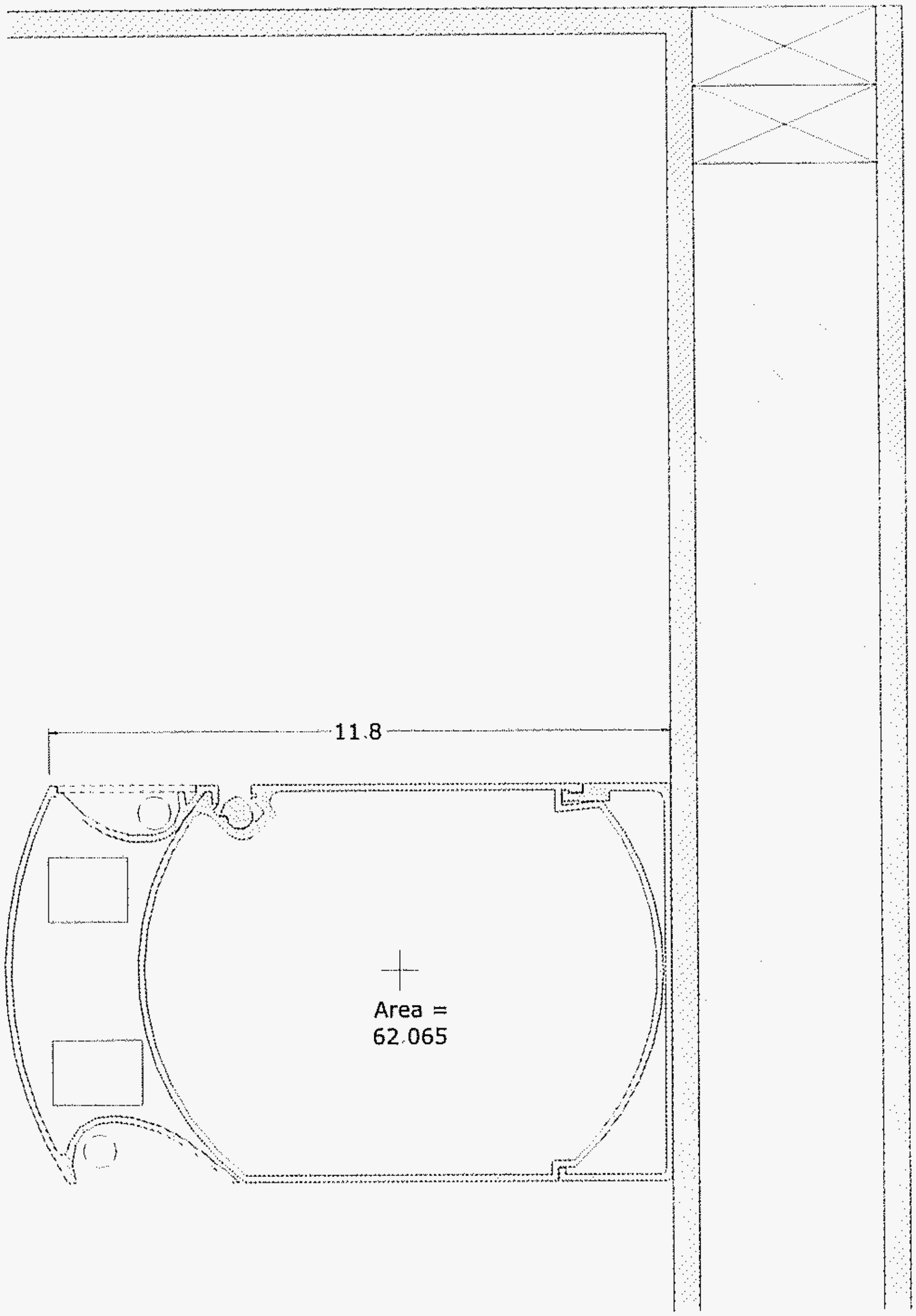
Modern Profile with Round Bottom



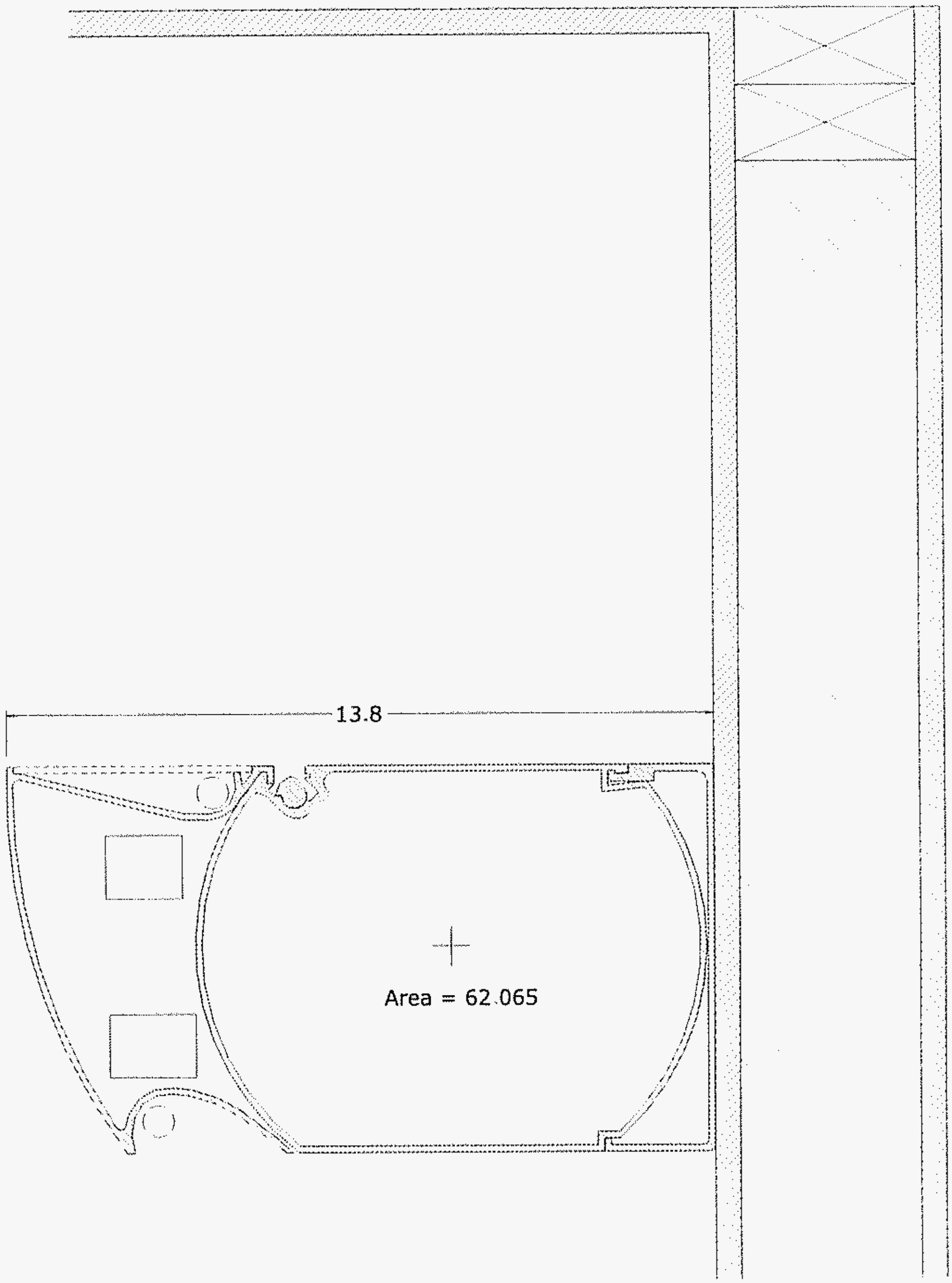
Modern Profile with Round Bottom
with ceiling- and wall-washing lights



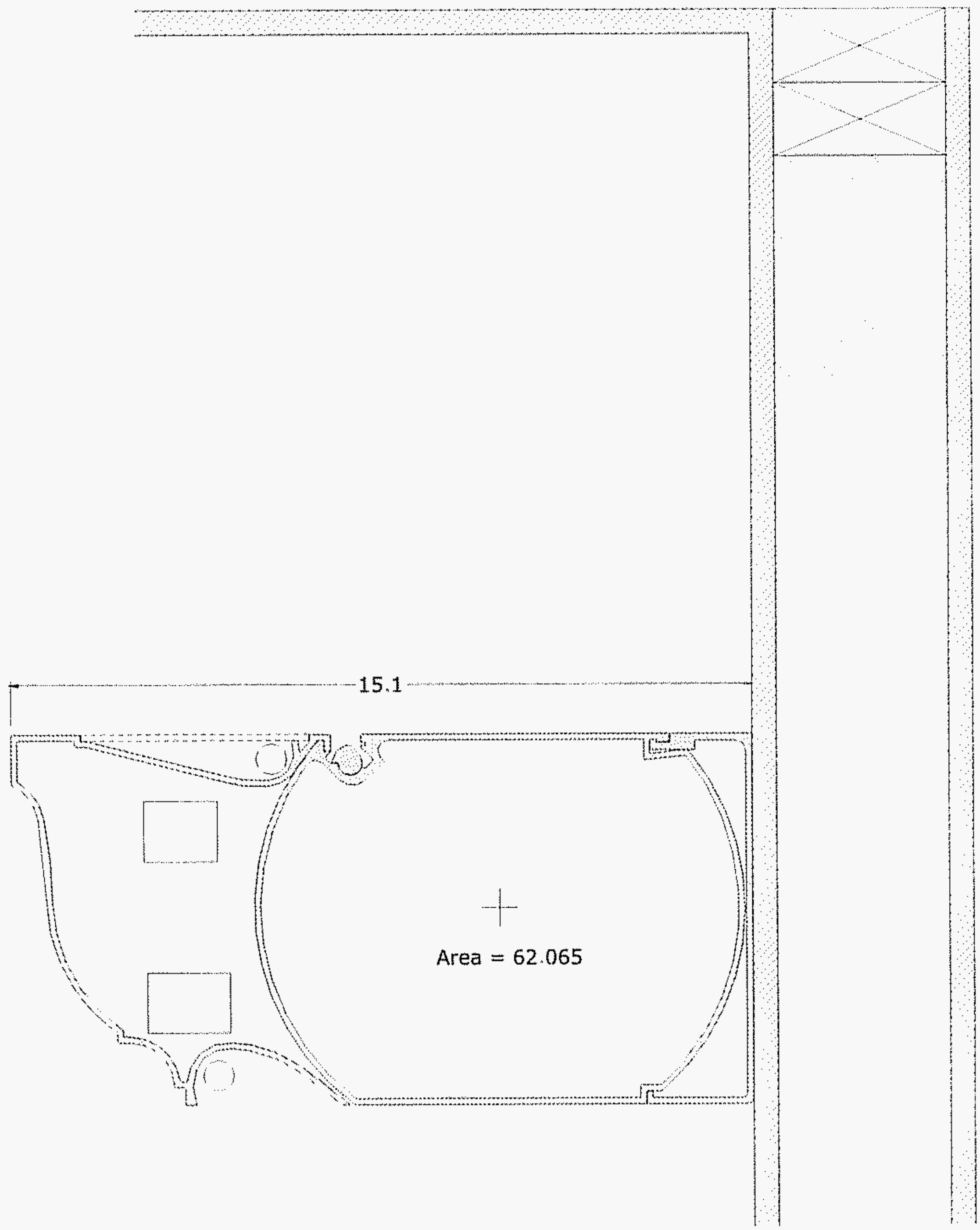
Modern Profile with Flat Bottom



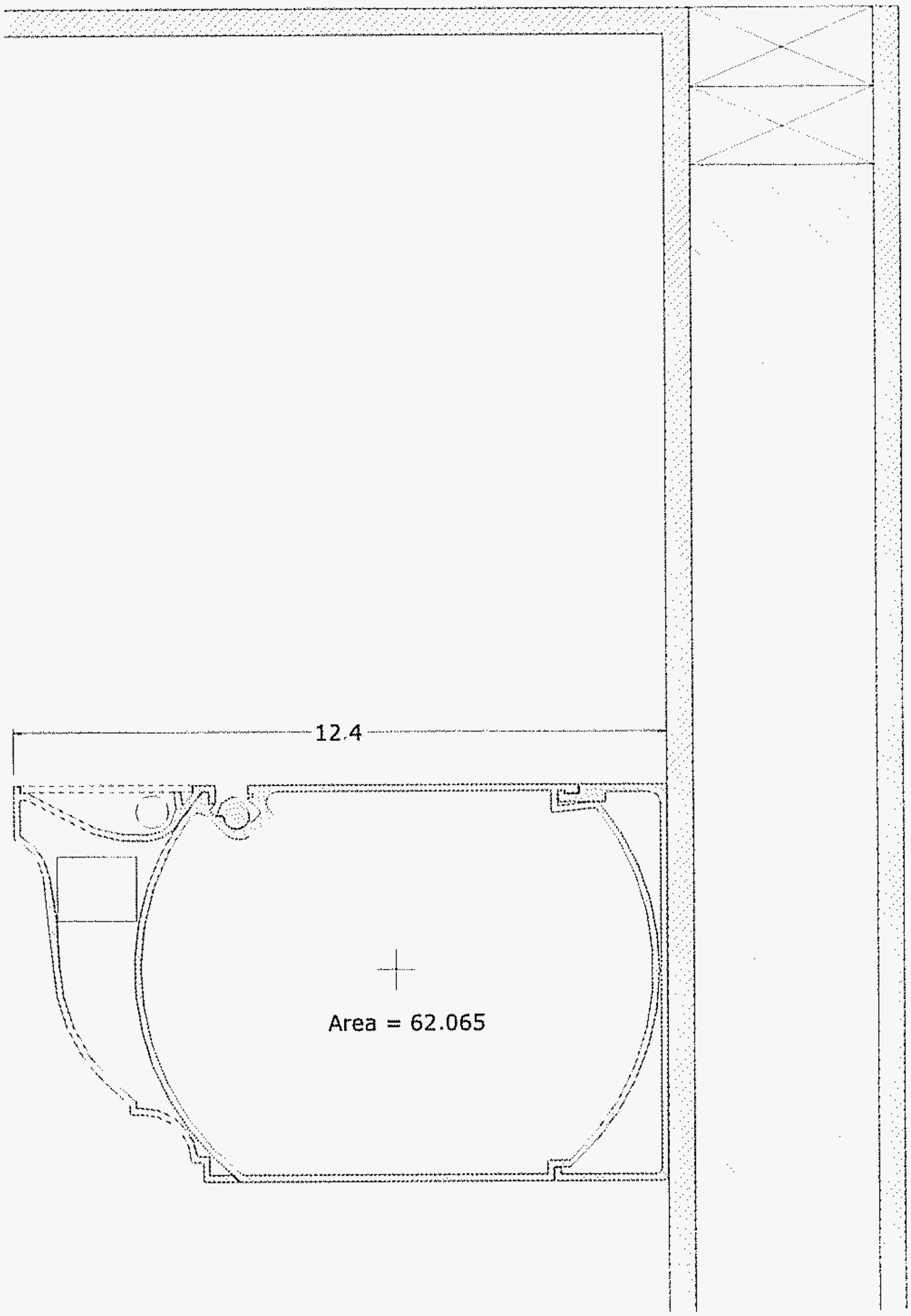
Modern Profile with Flat Bottom
with ceiling- and wall-washing lights



**Modern Profile with Flat Bottom
with ceiling- and wall-washing lights
with alternate face profile**



Classical Profile
with ceiling-washing and wall-washing lights



Classical Profile
with ceiling-washing lights

Circulation principles

The network of ducts for distributing air in buildings resembles the network for sap flow in trees. That is, it is a treelike, branching network in which the size of the ducts decreases with decreasing flow. Typically, we refer to the major ducts in the system as trunk lines, which feed air to the minor ducts, which we call branch lines. Because residences are so small, the network of ducts will only occur at two levels, with a single trunk line and multiple branch lines. In some houses, the trunk line is nothing more than a plenum volume mounted above the air handling unit. Branch lines emerge from this plenum volume and run directly to the remote spaces of the house where thermal conditioning is required. Using this system, all the connections are concentrated at the plenum volume which makes making the connections simple. Typically, the branch ducts are flexible ducts that can be snaked easily through and around a maze of obstacles, such as the web members of roof trusses.

The CorniceAire system presents a challenge not encountered with flexible duct systems: The CorniceAire duct system resembles a grid network more than a tree structure. For both aesthetic and economic reasons, there are limitations to the size of the CorniceAire Duct, which means that making any part of the grid act as a trunkline is a challenge. In thinking about this, the following design rules apply:

1. Locate the delivery system (i.e., the air-handling system) as close to the center of the grid as possible. In this way, the distance to any remote parts of the network will be minimized, thereby reducing the size of ducts necessary to get the air to those remote locations. Another way of thinking about it is that the more parts of the grid intersecting at the air-handling unit, the greater the cross sectional area of duct available to carry air away where the air flow rate is the greatest.
2. Think in terms of opportunities to create plenum volumes at, or near, the air handling unit. These plenum volumes can act as the trunkline leading to many parts of the CorniceAire Duct grid. For example, a closet provided for the air-handling unit automatically provides an overhead volume that can be used as a plenum to accommodate the high flow rate at the air-handling unit. Other spaces can also afford opportunities for the creation of plenum volumes. For example, a corridor, which is a kind of trunkline for human circulation, can also serve as the trunkline for the air distribution system. This will result in a lower ceiling height in the corridor, which will typically not be disturbing if the corridor is not too long. (Normally, the small size of a residence allows short corridors to afford access to all the rooms on a floor.) A lower ceiling in the corridor (or the entry to a house) creates a kind of psychological compression, which is followed by a psychological decompression that occurs when one passes from the corridor into a room with the normal ceiling height. This enhances the sense of shelter, making the house feel cozier. It can also enhance the spatial quality of the rooms.
3. Insulate the plenum volumes to R5 on all surfaces to make sure that the air entering the duct network remains thermally conditioned.
4. Use a variety of CorniceAire Duct cross sections, with the largest cross sectional areas occurring near the air handling unit and smaller cross sectional areas in the remote parts of the network.

    As a rule:

    Provide at least 0.133 in^2 of duct cross-sectional area per 1 ft^2 of floor area being thermally conditioned by the duct.

    Keep in mind that where one duct terminates in the back of a second duct which forms a T-joint, each leg of the second duct should be treated as a separate flow path with separate floor areas being serviced by each flow path.
5. Insulation elements are provided for the top of all CorniceAire Ducts mounted next to the ceiling and insulated elements are generally recommended for the tops of all Ducts, including those mounted lower in the wall for use as shelves. Insulation on the top is the most effective in suppressing convective transfer from the ducts to the surrounding air, reducing heat loss through the ceiling, and assuring that air projected into the room is thermally conditioned.
6. Use insulation on both the top and bottom of the CorniceAire ducts that are servicing spaces further down the line, to assure that the air arriving at the remote

parts of the network is properly thermally conditioned. In other words, only ducts at the last room along a delivery line should be without insulation both top and bottom.

7. Keep duct runs as short as possible. This keeps the initial cost of the system down and improves the thermal quality of the air delivered to the occupied spaces by reducing the duct runs along which losses can occur.
8. Air only needs to be delivered from one side of a room for rooms of width 14 feet or less.[1] In fact, delivering air from two sides may reduce comfort levels, since air from opposing sides tends to pile up in the center of the room and then descend downward on the occupants head, rather than circulate gently around near the surfaces of the room. Of course, for aesthetics or lighting reasons, the owner may desire to have the duct system on all sides of the room. However, air delivery slots and air controllers only need to be supplied on one side of the room.
9. Delivery air from ducts mounted on interior walls is generally preferred for two reasons: 1. this projects the air towards the perimeter regions of the room, which tends to produce greater thermal uniformity throughout the room and 2. keeping the ducts away from exterior walls reduces losses through the building envelope. This last issue is particularly a concern in houses where the ceiling insulation is not as thick near the perimeter of the attic. Thin insulation near the perimeter of the attic is common, since soffit vents (to feed air circulation to the attic) are kept clear by holding the insulation back from the perimeter of the attic. Putting the CorniceAire duct on the outer wall mounts it where the thermal envelope is often most compromised. This clearly undermines the primary motive for the CorniceAire Duct, which is to keep the ducts well within the thermal envelope of the building.
10. For most rooms, dual air controllers should be provided (one controlling flow out of the first half of the duct and the other controlling the flow out of the second half of the duct) to allow for fine tuning of both the spatial distribution and the rate of the flow.
11. The common practice of carelessly over-sizing the thermal plant should be avoided. Avoiding over-sizing will reduce the initial size and cost of the thermal plant, reduce the initial size and cost of the ducts, reduce fan power and improve system efficiency by reducing the cycling rate for the condenser and fan-coil units. The CorniceAire duct system will work very well with low flow rates and should be designed accordingly. To determine the heating load, cooling load, and required quantity of air, you must calculate the energy balance of the residence. This can be done using manual calculations or with a computer program, such as RezCalc from Carrier Corporation. This program can account for ducts located in the conditioned space by setting the "duct multiplier" to 1, to indicate that there are no duct losses. The HVAC unit should be sized based on the results of the energy balance. (The allowance for no duct losses should reduce the required unit size by 15% to 30% compared to a normal system that is ducted in the crawlspace or attic respectively.) Flow can be determined on a room-by-room basis by doing a room-by-room energy balance or by taking a total residence energy balance and applying the following formula:

   $F_R = F_T \times (A_R / A_T)$ where:

   F_R = room flow
   F_T = total flow
   A_R = room area
   A_T = total area

[1] All of these design guidelines are based on testing that has been done in a house with R-19 walls, R-30 roof, and double-pane windows, in Raleigh, NC. These guidelines only apply to buildings that meet these thermal envelope standards. Mention is made of this at this time, simply to note that with sufficiently high standards of thermal envelope integrity, a comfortable, spatially uniform thermal environment can be maintained with gentle air flow from the interior walls of each room, with out delivering conditioned air through ducts running all the way to the exterior walls.

Once the required room flow is calculated, the required <u>length</u> of the <u>slotted</u> CorniceAire duct delivering air to the room can be determined by multiplying the total required flow for the room by the constant:

$$\frac{0.1 \text{ linear foot of slotted duct}}{cfm}$$

12. The following table shows a sizing chart for CorniceAire ducts.

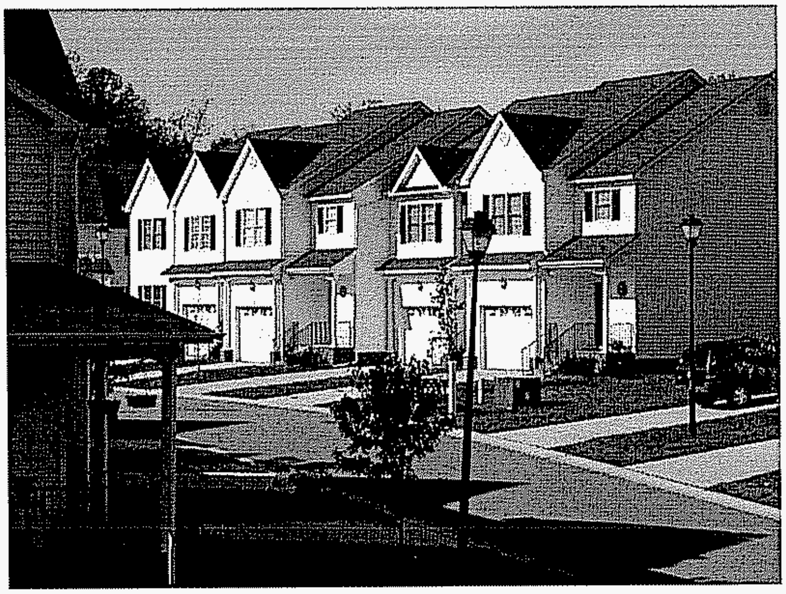
CorniceAire Duct Sizing

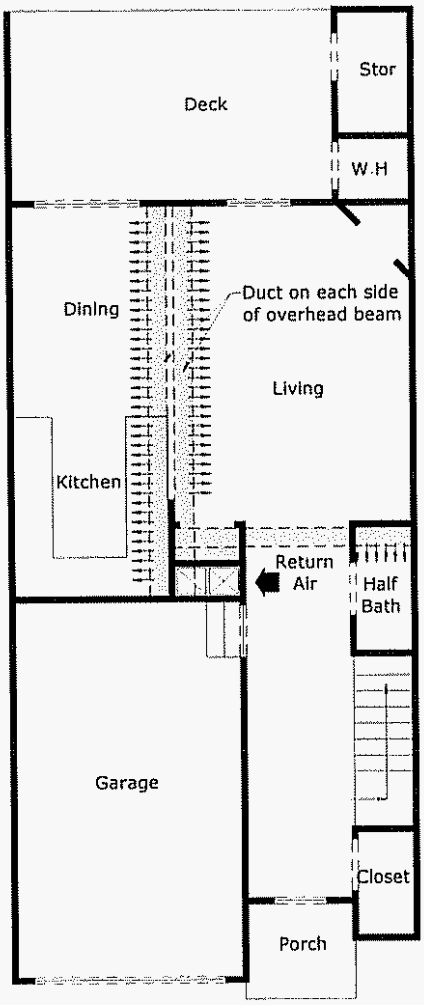
Type	area *sq. in.*	flow *cfm*
classical, small	34.9	100
classical, medium, insulated	39.1	150
classical, medium	42.8	150
classical, large, insulated	54.6	200
classical, large	58.3	250
Modern, flat bottom	62.1	250
Modern, round bottom	66.1	300

The required flow for each room is known based on the energy balance. A duct should be chosen that would deliver at least that amount of flow. For example, suppose a room requires 125 CFM. This amount of flow can be delivered by any 1 (one) CorniceAire System duct except for the small classical style, or by two small classical style ducts. Depending upon the configuration of the room it may be desirable to supply the room using two ducts, but it would be more cost effective to supply this room with one duct. Required flows through a room should account for any rooms that are downstream of that room. In other words, a duct that supplies a room requiring 125 CFM and then a room requiring 50 cfm should be of sufficient size to accommodate 175 CFM. Duct size for this situation could remain constant but for economy the duct size could be reduced as the downstream flow requirement decreases.

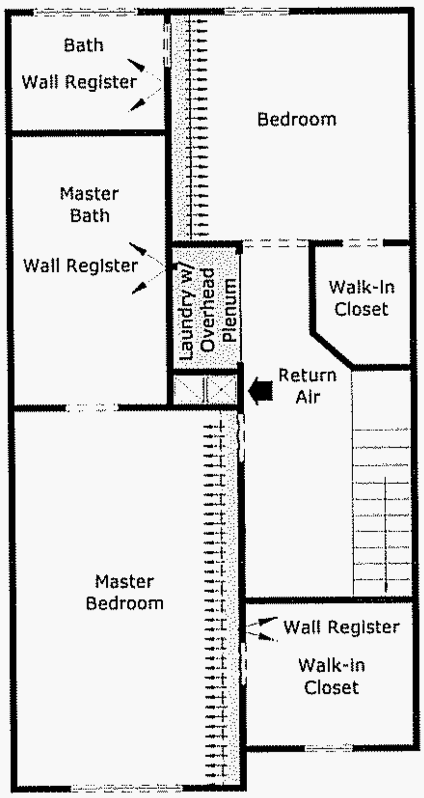
13. In bathroom spaces, standard diffusers mounted in the wall may in some cases be preferred to a run of CorniceAire Duct. These diffusers will be cheaper and they are typically quite capable of distributing air throughout the small volume of a bathroom. They have less exposed surface for condensate to form, which is advantageous during the summertime, when cool air being delivered to the bathroom has a strong tendency to condense moisture created by showers and bathtubs. If a CorniceAire Duct is used, particularly one with a built-in lighting system, then fully enclosed showers would be recommended to reduce the amount of moisture migrating to the CorniceAire Duct.
14. Once the entire system is installed, performance testing is recommended. The system should be qualitatively analyzed for noise, drafts, and other indicators of comfort. Also, the fan pressure difference should be verified to be within the design operating range of the fan (usually 0.2 to 0.6 in of water). The system should be within this range, but adjustments to the amount of slotted duct may be needed to bring the system into the range.

The following pages contain four design examples, including photos or elevations drawings and floor plans with duct layouts. In each case, the essential air-handling part of the duct is shown with dashed lines (to indicate that they are overhead) and hatching. CorniceAire Ducts can also be included in other parts of the room, for visual effect, but those parts are not indicated in these drawings, which are focused on the functional aspects of the system.



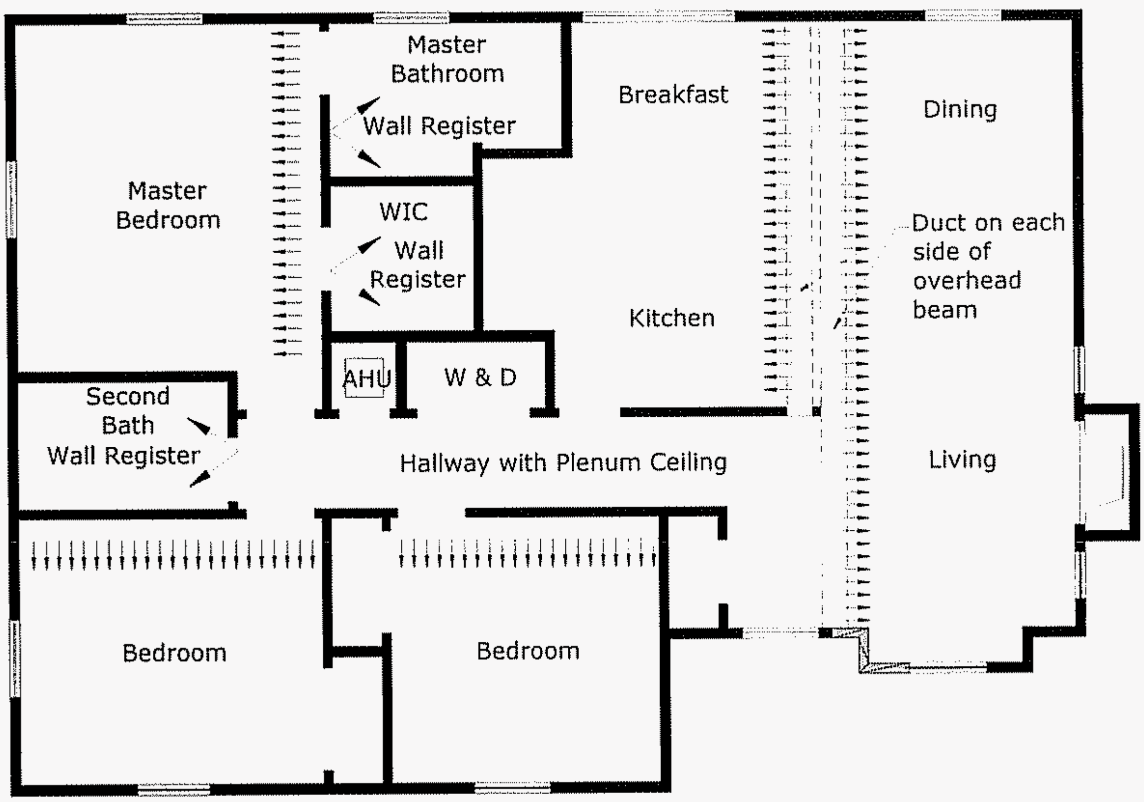


First Floor

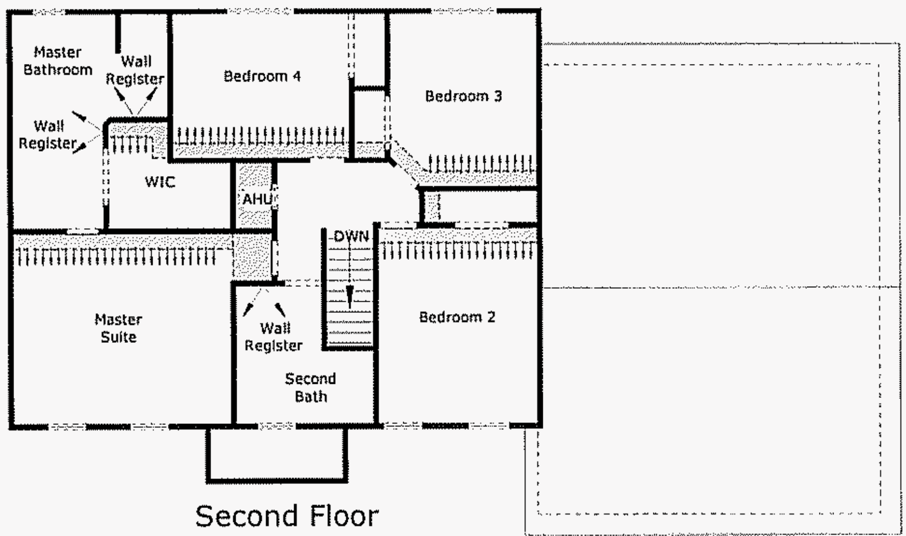


Second Floor

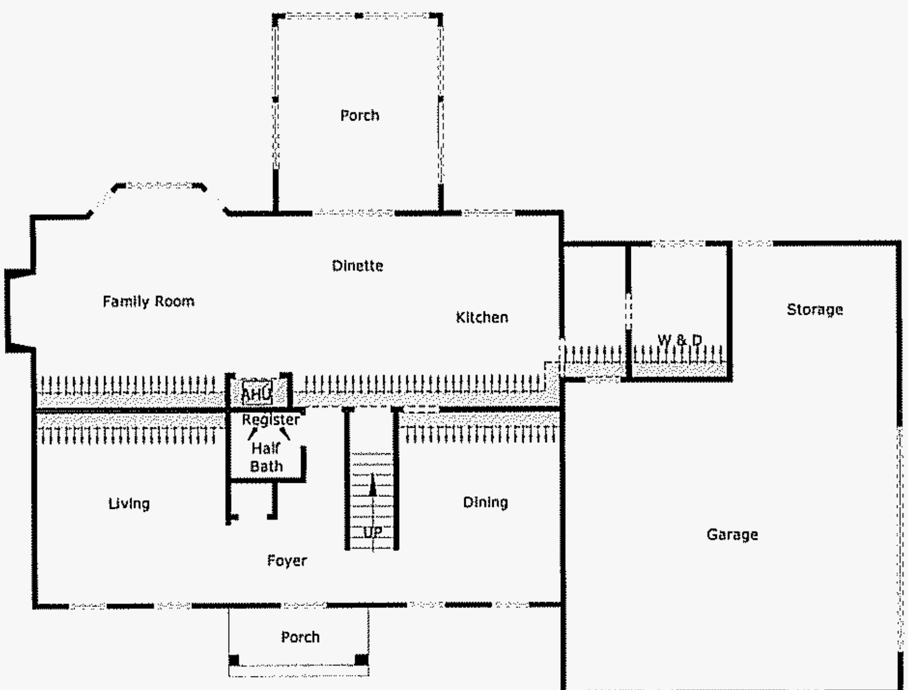
Design Example 1



Design Example 2

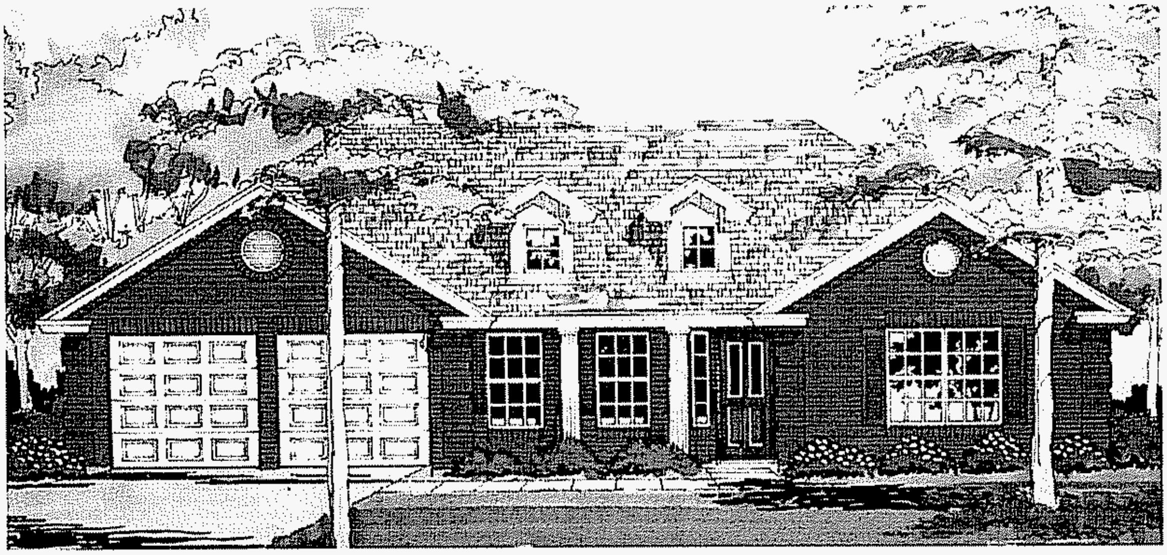


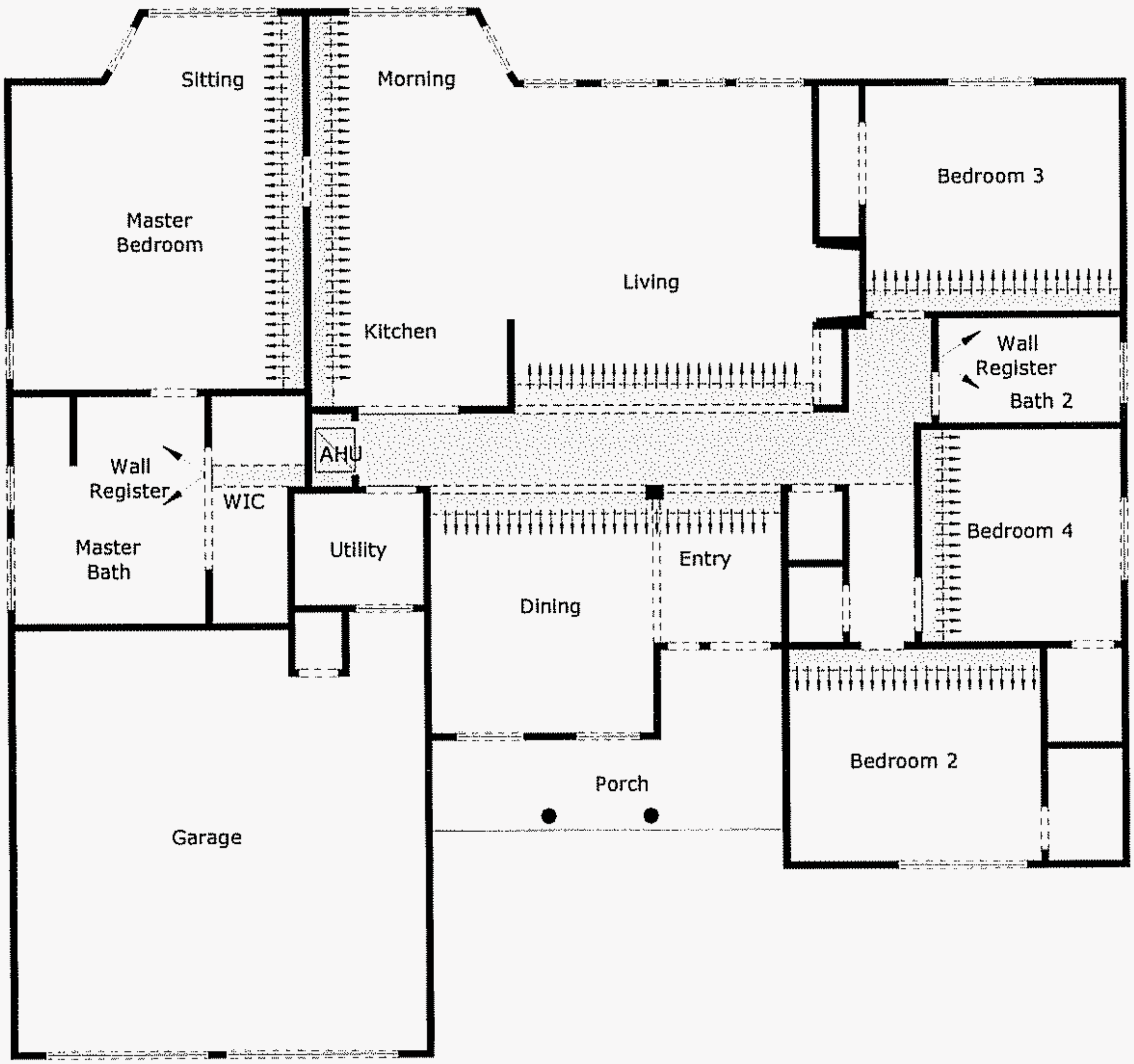
Second Floor



First Floor

Design Example 3





Design Example 4

Installation procedures

For mounting at the ceiling level, the top of the hanger can be screwed directly to the top plate of the wall. In this application, alignment of the hanger is achieved by pressing the top of the hanger against the ceiling. No leveling line is required.

To mount the CorniceAire lower on the wall for use as a shelf, the hanger must be screwed to the studs. In this case, it is important to establish a level line for the top of the hangar.

The hanger is somewhat flexible and will bend to conform to a crooked wall. However, the CorniceAire Duct is not flexible and any crookedness in the hangar element will prevent the hook edge on the Duct from properly engaging the support edge on the hanger. Therefore, a very straight edge, set horizontal, is required as a gage to make sure that the hanger is straight. Shims should be used behind the hanger to allow the screws to be pulled up tight without bending the hanger.

If there are mitered corners, these should be hung first.

Connector elements should be inserted in the ends of the duct, before the duct is hung. Then the connector elements should be slid out of the end of the duct to engage the adjacent elements in the system.

The air controller is dropped into the slot on the duct. Make sure the air controller is properly oriented before inserting it.

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TAV Fee

TAV Fee	Cost	Action
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